The Floodplain Risk Methodology (FRM):
A suite of tools to rapidly assess at the regional scale the impacts of groundwater inflows and benefits of improved inundation on the floodplains of the lower River Murray

Report to the River Murray Catchment Water Management Board

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The Floodplain Risk Methodology (FRM): A suite of tools to rapidly assess at the regional scale the impacts of groundwater inflows and benefits of improved inundation on the floodplains of the lower River Murray

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Acknowledgements

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Executive Summary

The native riparian vegetation communities on the floodplains of the lower River Murray in South Australia are suffering severe health decline. Recent mapping identified that 41% (40,000 ha) of the floodplain in South Australia was severely degraded by soil salinisation (Walker et al., 2005). Raised weir pool levels and the development of irrigation areas adjacent to the floodplain has increased rates of evapotranspiration or groundwater discharge (and hence increased movement of salt up into the plant root zone; Jolly, 1996). River regulation has also led to reduced frequency and duration of the floods that leach salt from the plant root zone. To protect remaining floodplain and wetland vegetation, there is a need for modelling tools that identify areas where irrigation and weir pool levels increase the risk of salinisation and where flow management is most beneficial for floodplain vegetation.

In response, the River Murray Catchment Water Management Board (RMCWMB) commissioned the project "Assessing Current and Future Impacts of Land Management Induced Groundwater Discharge on Floodplain Health" in partnership with CSIRO Land and Water, the Department for Environment and Heritage (DEH) and the Department of Water, Land and Biodiversity Conservation (DWLBC). In addition to conducting floodplain vegetation floristic and health mapping (DEH), the project developed the Floodplain ImPacts model (FIP, Overton et al., 2003). The FIP model was designed to be sufficiently simple to be applied with Geographical Information System (GIS) applications, yet powerful enough to determine the groundwater discharge patterns through cross-sections of the River Murray floodplain.

This report describes the advances made to the original FIP model through the development of SIMPACT2, the Floodplain Wetland ImPacts (FWIP) model and the Floodplain Risk Methodology (FRM). The mathematics of the FWIP model was revised to describe the effects of floodplain backwaters, such as wetlands, anabranches and oxbows, on groundwater discharge through the floodplain. The FWIP model predicts floodplain areas at risk of salinisation due to seepage at the break of slope at the edge of the river valley, salinisation risk on the highland side of the wetland, in the wetland and on the river side of the wetland, and groundwater flows or salt loads to or from the river and wetlands.

Groundwater inflows to the floodplain from the regional aquifers beneath the highland used in the original FIP model (Overton et al., 2003) may have under-predicted the impacts of some current irrigation. SIMPACT2 was modified to estimate increased inflows due to the ‘legacy of history’ (i.e. inflows delayed by the movement of water through the deep soil profiles and groundwater system) from irrigation and vegetation clearance. These groundwater inflows were distributed along the edge of the river valley as groundwater inflows to the FWIP model.

The FIP model did not predict those areas where groundwater discharge through the floodplain surface as evapotranspiration might be mitigated to some degree by flooding. This was addressed by combining the outputs of FWIP and FIM (Flood Inundation Model; Overton, 2005) to develop the FRM (Floodplain Risk Methodology). The FRM is a rapid assessment approach that brings together our current knowledge of the interactions between salinisation risk associated with groundwater discharge and the benefits of periodic flooding for long term floodplain vegetation health.

At the time the FIP model was completed, vegetation health maps were only available for between Lock 3 and 4. The completion of the DEH vegetation floristic and health survey meant that more rigorous testing of the FWIP model predictions was carried out. The FIP model did not apply to areas with irrigated floodplains, in particular the dairy flats downstream of Mannum. This was addressed by removing the dairy flats downstream of Mannum from the FWIP model.
Floodplain Wetlands ImPact Model (FWIP)

The FWIP model was used to predict salinisation risk, seepage areas and salt loads to the river and wetlands in four groundwater inflow scenarios that were used as inputs to the FRM and are discussed below:


   The FWIP model prediction that 36% of the floodplain vegetation was at high FWIP salinisation risk in 2000. This was comparable to the 41% of the DEH vegetation mapping that was classed as unhealthy trees, dead trees or halophytes, which are indicative of floodplain salinisation. Wetlands were predicted to have a high FWIP salinisation risk, but were dominated by herbaceous / wetland species, which may be related to flooding, which was not included in the FWIP model, but was addressed by the FRM. While there was not a comprehensive dataset to compare the location of observed to predicted seepage areas (4.4% of the modelled floodplain edge), many of the predicted seepage areas were adjacent to the irrigation areas and appear to have been correctly predicted. The patterns of salt loads and total salt loads to the river and wetlands (1,186 tonnes d⁻¹) were comparable to available Run-of-River salinity surveys, but the absolute values were higher than the Run-of-River values and those predicted by the MSM–BIGMOD model (MDBC, 2005b). This may have been related to the lack of salinity data for the floodplain aquifer or due to the absence of large floods that mobilise salt to the river over the past decade.

2. **Current irrigation and clearing (2100)**

   Groundwater inflows to the river valley were predicted to double between 2000 and 2100 from ‘legacy of history’. The FWIP model predicted that between 2000 and 2100, the area of floodplain vegetation at high FWIP salinisation risk would increase by 2,889 ha (9.1%), seepage would increase by 70 km (166.7%) and salt loads to the river and wetlands would increase by 977 tonnes d⁻¹ (82.4%). The location of most of the FWIP salinisation risk areas upstream of the nearest weir and adjacent to existing irrigation areas suggest that these floodplains have limited capacity to discharge more water by evapotranspiration, meaning that additional groundwater inflows were predicted to be discharged as seepage and as groundwater discharge to the river and wetlands.

3. **Irrigation Expansion from Prior Commitments (2100)**

   The model was then used to demonstrate the impact of a 6,780 ha irrigation expansion from potential ‘prior commitment’ claims between the Border and Lock 1 that commenced in 2010. Groundwater inflows to the river valley in 2100 were predicted to increase by 7.8% compared to flows from the current irrigation and clearing (2100) scenario. The FWIP salinisation risk was predicted to increase by 306 ha (0.4%), seepage risk by 11 km (9.8%) and the salt loads to the river and wetlands by 133 tonnes d⁻¹ (6.1%) compared to the current irrigation and clearing scenario (2100). Seepage risk was almost three times greater and the salt loads to the river and wetlands almost double those predicted for the current irrigation and clearing (2000) scenario. The location of the ‘prior commitment’ irrigation claims near areas where the floodplain aquifer was already ‘full’, due to the high groundwater inflows from current irrigation and clearing and high weir pool levels meant that additional groundwater inflows were discharged as seepage at the break of slope and into the river and wetlands as salt loads.

4. **Proposed Salt Interception Schemes (2100)**

   The final scenario predicted the benefits that may arise from the commissioning of all of the currently proposed salt interception schemes in addition to the current salt interception schemes. The proposed salt interception schemes were predicted to decrease groundwater inflows to the river valley by 29.1% by 2100. The FWIP model...
predicted that this would decrease FWIP salinisation risk by 9,500 ha (27.9%), seepage by 35 km (31.3%) and that salt loads to the river and wetlands by 812 tonnes d\(^{-1}\) (37.5%) by 2100. Overall, the predictions suggested that salt interception could be highly beneficial in reducing the salinity risk to the floodplain and wetland. However, it was noted that the large amounts of salt stored within the floodplain would need to be removed before the benefits to the vegetation and wetlands would be realised.

**Floodplain Risk Methodology (FRM)**

The first step in the development of the FRM was to combine the broadscale ‘FWIP salinisation risk’ with the finer scale ‘weir pool salinisation risk’. ‘Weir pool salinisation risk’ was defined as salinisation risk associated with the depth of the water table due to river level alone. Each of the 32,000 vegetation polygons along the whole of the South Australian River Murray floodplain were assigned one of six possible salinisation risk classes (high or low FWIP salinisation risk and high, medium or low weir pool salinisation risk). These six possible salinisation risk classes were grouped into three management scenarios:

1. **Salt Interception Scheme (SIS) to control groundwater inflows**
   
   These areas were at high FWIP salinisation risk, but had medium to low weir pool salinisation risk, which means they may benefit from salt interception to reduce the rate of groundwater discharge and salinisation risk.

2. **Protect from future salinisation risks**
   
   These areas were at low FWIP salinisation risk and had medium to low weir pool salinisation risk, which means that increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may be a threat.

3. **Limited management options available**
   
   These areas had a high weir pool salinisation risk, which means that floodplain groundwater levels may be difficult to manage because they are close to river level.

The next step in the development of the FRM was to define flooding classes. To do this, the extent of the present-day ‘active’ floodplain was determined based on the return period (1 in 7 years) of a flow that inundated ~95% of the Red Gum and Black Box communities on the Chowilla floodplain under natural conditions. Under current conditions, this recurrence interval is equivalent to a flow of ~70,000 ML d\(^{-1}\), which is also the maximum flow for which viable engineering options can be used to ‘water’ the floodplain. Therefore, a 70,000 ML d\(^{-1}\) flow or less that defines the ‘active’ floodplain and represents a critical ecological and engineering threshold in the lower River Murray in South Australia was used for the FRM scenarios. The FRM was applied to five example scenarios; two scenarios for current irrigation and clearing in 2000 and 2100 and three scenarios that demonstrate the way the methodology could be applied to examine the impacts and benefits of potential management options. The results of these five scenarios are summarised below:

1. **Current irrigation and clearing (2000) – 70,000 ML d\(^{-1}\) flood**
   
   The FRM showed that most of the healthy and unhealthy trees were in the low FWIP, medium to low weir pool salinisation risk classes, but were outside of the 70,000 ML d\(^{-1}\) flood, meaning they were more difficult to flood. These classes are a priority for protection from future salinisation risks. More of the healthy than unhealthy trees were in the high weir pool salinisation risk and ≤ 70,000 ML d\(^{-1}\) flood class, where limited management options are available. However, this may indicate that these trees overlie relatively fresh groundwater that is maintained by frequent flooding. A strong relationship between the flooding and weir pool salinisation risk classes was observed.
2. **Current irrigation and clearing (2100) – 70,000 ML d<sup>-1</sup> flood**

The FRM predictions for current irrigation and clearing (2100) and a 70,000 ML d<sup>-1</sup> flood showed that 2,000 ha of vegetation that was at low FWIP, medium to low weir pool salinisation risk in 2000, or ‘Protect from future salinisation risks’ was at high FWIP salinisation risk in 2100. Almost all of this vegetation was outside of a 70,000 ML d<sup>-1</sup> flood, meaning that it would be difficult to ameliorate the increased FWIP salinisation risk with flooding. This class contained most of the healthy (40% of the healthy trees) and unhealthy (54% of the unhealthy trees), which means that an additional ~1,000 ha of healthy and unhealthy trees were at greater risk of salinisation due additional groundwater inflows from ‘legacy of history’ under the current irrigation and clearing scenario in 2100 than in 2000.

3. **Irrigation Expansion from Prior Commitments (2100) – 70,000 ML d<sup>-1</sup> flood**

The FRM predictions for Irrigation Expansion from Prior Commitments (2100) and a 70,000 ML d<sup>-1</sup> flood were similar to the increased salinisation risk from the ‘legacy of history’ for the current irrigation and clearing (2100) scenario. Over 2,200 ha of vegetation that was designated as ‘Protect from future salinisation risks’ under current irrigation and clearing (2000) was predicted to be at high FWIP salinisation risk in 2100 under the Prior Commitments (2100) scenario, meaning that a Salt Interception Scheme (SIS) would be necessary to control groundwater inflows to protect this vegetation.


The maximum possible weir pool raising and flow scenario inundated less than a quarter (24%) of the floodplain vegetation upstream of Lock 1, compared to a 70,000 ML d<sup>-1</sup> flood that covered almost half (42%) of the area. This scenario can deliver flows to ~5,000 ha (14%) of healthy and unhealthy trees and most of the wetland species (~9,100 ha or 64%). Most of the healthy (13,878 ha or 84%) and unhealthy (18,154 ha or 89%) trees were outside of the area inundated by the weir pool raising scenario. Most of these trees (56% of healthy and 63% of unhealthy) were at low FWIP, medium and low weir pool salinisation risk, meaning they should be ‘Protected from future salinisation risks’. Therefore, over 10% of trees (13% of healthy and 17% of unhealthy) were at high FWIP salinisation risk in the ‘Salt Interception Scheme (SIS) to control groundwater inflows’ management scenario.

5. **Proposed Salt Interception Schemes (2100) – 70,000 ML d<sup>-1</sup> flood**

The FRM showed that over 6,100 ha (8%) of vegetation that was classed as high FWIP salinisation risk under the current irrigation and clearing (2100) scenario had a low FWIP salinisation risk under the Proposed SIS (2100) scenario. This included over 3,500 ha of healthy and unhealthy trees. However, most of this vegetation was outside of a 70,000 ML d<sup>-1</sup> flood, which means that it may be difficult to remove salts stored in the soil profile in the absence of large floods.

**Recommendations**

The FRM should be considered as a rapid assessment tool whose role is to identify areas where irrigation and weir pool levels increase the risk of salinisation, to prioritise areas for where collection of detailed data, modelling and analysis is likely to be required to support decision making, or as a policy or planning support tool to explore the implications of policy decisions. Notwithstanding the identified limitations of the FRM, it is the only methodology available for the whole of the River Murray floodplain in South Australia. As such, the FRM and the data sets contained within could be used to assist in the evaluation and reporting against resource condition targets and other aspirational goals contained within the various River Murray initiatives such as the RMWAP, MDBC Living Murray, and Floodplain Planning etc. It is recommended that consultation take place to resolve the long-term custodianship of the FRM and its data sets to ensure adequate training of users and the ability to update the data and improve the component models within the FRM as new information becomes available. The report also contains technical recommendations to improve data quality and consistency across the whole of the River Murray floodplain in South Australia.
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Table C1. FRM GIS field descriptions, typical values and units
1 Introduction

The native riparian vegetation communities on the floodplains of the lower River Murray in South Australia are suffering severe health decline. These remnant communities are of considerable ecological significance (several are listed under the 1971 Ramsar Convention on Wetlands) and the floodplains themselves are highly valued by the community for activities such as bird watching, boating, fishing, and general recreation.

The lower reaches of the River Murray naturally act as a drain for the highly saline regional groundwater systems of the Murray Basin (Figure 1). Much of the regional groundwater flow to the River Murray passes through the floodplains within the river valley (Barnett, 1989). The high groundwater salinities in this region mean that the floodplain soils naturally contained high amounts of salt. This, combined with the semi-arid climate with very irregular flooding, meant that salt accumulated in the dry period between floods but was leached whenever inundation occurred, thus creating a dynamic equilibrium that was stable in the long-term, as evidenced by the ages of mature floodplain trees exceeding 100 years (see Slavich, 1997). However, the constantly high weir pools due to regulation of the lower River Murray since the 1920-30s has caused the naturally saline groundwater beneath the floodplains to rise closer to the surface thereby accelerating the rate at which salt is transported up into the root zone by capillary rise. The development of irrigation areas adjacent to the floodplain has also contributed to the rise in groundwater beneath them. River regulation has also led to reduced frequency and duration of the floods that leach salt from the plant root zone. The combined effect of these processes is long-term salt accumulation in the floodplain soils, which is the primary cause of the vegetation dieback (Figure 2). Recent estimates derived from on the Department for Environment and Heritage (DEH) floodplain vegetation floristic and tree health mapping (Smith and Kenny, 2005) suggest that ~40% (40,000 ha) of the floodplain in South Australia is severely degraded by soil salinisation (Walker et al., 2005), and it is probable that this will increase in the future.

Figure 1. Map showing the regional groundwater flow directions and salinity in the lower River Murray region.
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The South Australian River Murray Salinity Strategy (DWR, 2001) has proposed several salinity management options to ameliorate the impact of salinity on floodplain and wetland health, in addition to existing measures to address in-stream salinity impacts. These salinity management options include flow management, on-ground works and the establishment of floodplain and wetland protection zones to ensure new irrigation development will not impact on wetlands and floodplains of high conservation value. Many of these actions will be carried out under the River Murray Water Allocation Plan (WAP; RMCWMB, 2002) that was adopted on 1 July 2002. A key objective of the River Murray WAP is that the transfer, allocation and use of water must not have adverse impacts on the health, biodiversity status or habitat value of floodplains, or wetlands of conservation significance. Hence there is a need for a modelling tool to assist in the prediction of the impact of current and future irrigation developments and river management on floodplain salinisation.

In response, the River Murray Catchment Water Management Board (RMCWMB) commissioned the project "Assessing Current and Future Impacts of Land Management Induced Groundwater Discharge on Floodplain Health" which was a partnership between the RMCWMB, CSIRO Land and Water, DEH and the Department of Water, Land and Biodiversity Conservation (DWLBC). In addition to carrying out floodplain vegetation floristic and health mapping (DEH), the project developed the Floodplain ImPacts model (FIP, Overton et al., 2003). The FIP model predicts floodplain areas at risk of salinisation due to seepage at the break of slope of the highland/floodplain and evapotranspiration across the floodplain. It was designed to be sufficiently simple to be applied with Geographical Information System (GIS) type applications, yet powerful enough to determine the groundwater discharge patterns through cross-sections of the River Murray floodplain. The model was applied spatially by discretising the floodplain into a series of representative cross...
sections (divisions) designed to represent the direction of groundwater flow across the
floodplain (Figure 3). Approximately 3000 divisions were created and were ~250 m wide at
the edge of the floodplain. The width of each division at the river’s edge varied greatly
depending on the geometry of the floodplain and the direction of groundwater flow across the
floodplain.

Overton et al. (2003) presented several example scenarios (broadscale increases in inflows
due to new irrigation, broadscale improvements in efficiency of current irrigation, and
groundwater lowering beneath the floodplain) which demonstrated the capability of the
model. However, at the time the FIP model was completed a number of shortcomings were
recognised and further development was recommended. This report describes the work
carried out to address these limitations. The major issues of concern with the original
version of the FIP model were:

1. The effects of floodplain backwaters, such as wetlands, anabranches and oxbows, on
groundwater discharge through the floodplain were not simulated in the model. This
was because the role that these water bodies play in intercepting saline groundwater
flowing towards the river was unknown, and the mathematics to account for these
effects had not been developed. It is possible to improve to the mathematics to
describe the effects of major permanent backwaters (one per floodplain division) and
the new mathematics developed in the current project are presented in Chapter 3 and
Appendix A. This revised version of the FIP model is called the Floodplain Wetland
Impacts (FWIP) model. It is important to note that there has been little improvement
in the field understanding of the connection between any of the major backwaters and
the underlying groundwater since the FIP model was first developed. As such,
estimates of the degree of connectivity for any given backwater has become another calibration parameter in the new version of the model described here.

2. Groundwater inflows to the floodplain from the regional aquifers beneath the highland were calculated using the highland aquifer parameters and the interpolated highland groundwater surface using Darcy's Law. Due to lack of field data these estimates were subject to some uncertainty and this is difficult to quantify. Moreover, the estimates reflected conditions in which the root zone drainage from areas of irrigation is contributing to the groundwater inflows to the River Murray valley. While this may be the case for irrigation that has been in place for a long period of time, it is possible that there are recent developments where this is not the case, and so the groundwater inflow impacts are yet to be felt (this is often referred to as the 'legacy of history'). As such, the FIP model may have under-predicted the impacts of some current irrigation. In terms of future impacts the scenarios presented were purely hypothetical, reflecting broad-scale changes in the region. In reality, future irrigation developments will occur in discrete locations at discrete times, as will improvements in irrigation efficiency. The SIMPACT2 model (Miles et al., 2001; Munday et al., 2004) was designed to predict the impacts of discrete new areas of irrigation on groundwater inflow to the river valley and as such would provide an appropriate means of predicting groundwater inflows to the FWIP model. However, it had not been applied to predicting inflows from current irrigation that have not yet occurred (i.e. ‘legacy of history’ inflows) or from clearance of native vegetation for dryland agriculture. Also, it did not have the ability to accurately define where the inflows to the river valley occur from an existing or new irrigation or dryland development, something that is crucial for the FWIP model. These shortcomings were overcome with further development of algorithms to post-process SIMPACT2 outputs and the application of new spatial data on the timing of existing irrigation developments and vegetation clearance for dryland agriculture. Descriptions of these new aspects in SIMPACT2 to address these issues are presented in Chapter 4.

3. The original FIP model and the new FWIP model were designed to describe groundwater discharge from the floodplain by evapotranspiration, and by inference the accumulation of salt within the floodplain soils and groundwater. It does not predict those areas where groundwater discharge from the shallow water table may be mitigated to some degree by flooding (as illustrated in Figure 2). Subsequent to the first version of FIP being completed, the Flood Inundation Model of Overton et al. (1999) and Overton (2005) was upgraded to cover the entire River Murray floodplain in South Australia. When combined with the DEH vegetation floristic and health mapping, the Flood Inundation Model provides a means of determining the flooding regime for all vegetation communities on the floodplain. Incorporation of this flooding information with the FWIP predictions of salinity risk arising from the current and future groundwater inflows predicted by the new version of SIMPACT2 allows the development of a Floodplain Risk Methodology (FRM). This is described in Chapter 5.

4. At the time FIP was completed, vegetation health maps were only available for the Lock 3 to 4, and so rigorous testing of the model was only carried out in this reach, as summarised in Overton et al. (2003) and described in detail in Holland et al. (2004). For the other reaches testing of the predictions was only carried out against Run-of-River salinity surveys and field observations of locations of seepage. With the subsequent completion of the DEH vegetation floristic and health survey, and the major changes to the model described here, more rigorous testing against all of the available data can be undertaken.

5. The model also does not apply to areas with irrigated floodplains (e.g. the dairy flats downstream of Mannum. This is not of particular concern, as these floodplains do not have large areas of native terrestrial vegetation. They also do not appear to be
undergoing salinisation to any degree, because the low irrigation efficiency (i.e. high root zone drainage) provides a means of keeping soil salinities low, and reducing the salinity of the underlying groundwater. Moreover, the complicated irrigation and surface/groundwater drainage channel systems cannot be modelled with the analytical approaches used in the FIP model. For these reasons this limitation has not been addressed, and so the downstream boundary of the model is Mannum.

The purpose of this report is to:

1. Describe in detail the improvements that have been made to FIP (the new FWIP model) and SIMPACT2 to address the above limitations and enable them to function together. SIMPACT2 itself has not been revised, rather new data and utilities have been developed to enable SIMPACT2 to estimate the impacts of ‘legacy of history’ irrigation and vegetation clearance on induced inflows, and to determine the distribution of these groundwater inflows to the river valley;
2. Describe and present the estimation of pre-irrigation/pre-clearing groundwater inflows to the floodplain which are added to the SIMPACT2 irrigation and clearing induced increases in inflows;
3. Present the predicted groundwater inflows to the floodplain from SIMPACT2 for current irrigation development conditions at the years 2000, 2020, 2050 and 2100. The predicted inflows for 2000 are compared with those from other sources;
4. Present the floodplain salinity risk predictions from FWIP under current irrigation development conditions at the years 2000, 2020, 2050 and 2100;
5. Describe the development of the FRM and make predictions at the years 2000 and 2100;
6. Describe three scenario examples of the use of FRM for potential use in floodplain planning policy development; and
7. Describe the outstanding limitations of the models and provide guidelines for their appropriate use.
2 Existing Models

In this Chapter we briefly summarise existing models that are applicable to the floodplains of the River Murray in South Australia in order to set the context for the remainder of the report.

2.1 MODFLOW Groundwater Models

Currently, regional scale groundwater models based on MODFLOW (McDonald and Harbaugh, 1996) are being used to estimate the flux of groundwater entering the river valley. However, within these regional scale models, floodplain processes are either not represented or cannot be modelled at the resolution required to refine management strategies to the scale of the individual floodplain. For example, the interception of groundwater by the floodplain (due to evapotranspiration) is known to decrease the salt load to the river at low flows (Jolly, 1996), however the regional models generally assume no interception, or that a fixed proportion of groundwater is intercepted, e.g. 30% (Barnett et al., 2002). While floodplain groundwater level fluctuations have been simulated with a number of analytical and numerical models (e.g. Narayan et al., 1993; Jolly et al., 1998; Armstrong et al., 1999; Bates et al., 2000; Middlemis et al., 2004; Yan et al., 2005a, b), none address the impact that shallow groundwater has on salinisation of floodplain soils. One notable exception is the recent study by Doble (2004) who successfully simulated groundwater interception and salt storage in the Bookpurnong floodplain using a modified version of MODFLOW-2000 (Harbaugh et al., 2000). This was made possible by the detailed hydrogeological, geomorphological and vegetation data that were available for this small (~500 ha) floodplain. Unfortunately this level of information is rarely available.

While complex numerical models such as MODFLOW-2000 could be developed for the entire ~100,000 ha of floodplains, it would be extremely time-consuming and the lack of detailed data would mean that dynamic processes would be simulated with much less confidence than for the Bookpurnong model. The heterogeneity of the floodplain hydrogeology and geomorphology cannot be modelled adequately with regional scale data (e.g. Barnett and SA Department of Mines and Energy, 1991) and therefore the underlying conceptual models and data inputs need to be simplified.

2.2 GIS-Based Floodplain ImPacts (FIP) Model

Given the impracticalities of applying MODFLOW models to the entire floodplain, a more feasible approach is to use an analytical model. The advantage of an analytical model is that relationships between floodplain variables such as floodplain width, river height, hydraulic conductivity and groundwater discharge processes can be developed. Not only would these relationships be useful by themselves, but they could be implemented in a Geographic Information System (GIS) framework to provide objective analyses of salinity risk at a sub-regional scale.

An initial attempt at designing a GIS-based methodology to assess the impact of river regulation, reduced flooding frequency and irrigation development on floodplains in the lower River Murray was made by Gabrovsek et al. (2002). It demonstrated the potential of relatively simple risk assessment approaches. However, this analysis was based on individual key risk factors, rather than a model describing groundwater discharge processes, as is required for prediction of current and future risks.

Holland (2002) and Holland et al. (2004) developed and tested an analytical model that describes floodplain groundwater discharge patterns by distributing groundwater inflows to the floodplain into discharge into seepage at the break of slope, evapotranspiration across the floodplain and as base flow to the river. The analytical model estimates were compared with equivalent MODFLOW estimates and found to agree ($r^2=0.998$) over a broad range of typical floodplain recharge and evapotranspiration scenarios. The model was then applied using regional scale data to the Lock 3 to 4 reach and was able to predict groundwater discharge patterns within the floodplain with a reasonable amount of certainty. It was
concluded that it could be used as a planning tool to assess potential impacts to floodplain and wetland vegetation and the river from irrigation developments and changes to river management and could therefore be applied more broadly.

The FIP model of Overton et al. (2003) was an extension of the analytical model of Holland (2002) and Holland et al. (2004). It was developed for the whole of the floodplain within South Australia, with the exception of the irrigated lower Murray swamps downstream of Mannum. FIP was implemented within a GIS framework to facilitate ease of testing and scenario prediction. The preliminary results from the model showed that it was useful for predicting impacts from future scenarios and thus would be able to inform policy for floodplain protection and salinity mitigation. An example of the model predictions is given in Figure 4. As discussed above, the impact of wetlands and oxbows, which may act to intercept groundwater within the floodplain, was not taken into account, and so further development of the mathematics underlying the model was recommended.

![Figure 4. FIP model predictions of floodplain risk for the area between Lock 3 and 4 under a 20% increase in current inflows due to increased irrigation. Areas of salinisation have been given a gradational colour based on the percentage of floodplain with groundwater within 2 m of the modelled surface (from Overton et al., 2003).](image-url)
The WINDS (Weighted INDex of Salinisation) model of Overton and Jolly (2004) is a powerful GIS-based tool for predicting floodplain soil salinisation in response to raised water tables and changes in the flooding regime. It was developed to make spatial predictions for the Chowilla floodplain of long-term changes in floodplain soil salinity, and by inference vegetation health, due to current conditions and for various groundwater and environmental flow management scenarios. Its implementation relied on the availability of spatial layers of vegetation communities; vegetation health; soil hydraulic properties; groundwater salinity and groundwater depth. While readily available for Chowilla, the soil physical and groundwater data do not exist for most other floodplains and this precludes its application on a regional scale, at least at this stage.

### 2.3 Flood Inundation Model (FIM)

The Flood Inundation Model (FIM) was developed by Overton et al. (1999) and Overton (2005) as a tool to predict the extent of inundation of the floodplain in South Australia (from the New South Wales border to Lake Alexandrina) for a given River Murray flow. The model was developed using a GIS, remote sensing and hydrological modelling. Flood inundation extents were monitored from Landsat satellite imagery for a range of flows, interpolated to model flood growth patterns and linked to a hydrological model of the river. The resulting model can make predictions on a 30 m x 30 m pixel for flows ranging from entitlement flow to a 1 in 13 year flood (102,000 ML d⁻¹) for any month and weir configuration, and has been independently tested using aerial photography to an accuracy of approximately 15% underestimate. The model allows prediction of impacts on infrastructure, wetlands and floodplain vegetation, allowing quantitative analysis of flood extent to be used as an input into the management decision process. Figure 5 shows an example of predictions made from the Flood Inundation Model.

![Figure 5. Example of the Flood Inundation Model predictions of the flows required to inundate the floodplain in the Cadell-Taylorville reach.](image-url)
2.4 SIMPACT Salt Load Assessment Model

SIMPACT is a GIS-based modelling framework aimed at simulating changes in root zone drainage below the root zone, time delays for recharge to the groundwater system and discharge to the river valley (discharge edge), which may result from a change in land use. The first version of SIMPACT (Miles et al., 2001) was developed to identify River Murray salinity impacts of potential irrigation development in highland irrigation areas. It focussed on comparing impacts at a regional scale by producing a river-wide perspective on where irrigation development would have higher and lower impacts. The model used a raster or grid cell (500 m x 500 m) approach to assess points on the landscape within 10 km either side of the Murray River.

SIMPACT2 was developed as part of the Riverland component of the South Australian Salinity Mapping and Management Support Project (Munday et al., 2004), and incorporated new unsaturated zone methods (Cook et al., 2004) to calculate lag times for root zone drainage to reach the water table, and a unit response equation (Knight et al., 2005) to assess the impact of the resultant increased recharge on discharge to the river valley. SIMPACT2 is not a replacement for MODFLOW. It models a single layer system describing the dynamics of unconfined aquifers, so that the impacts of a change in recharge rates (e.g. from irrigation development) can be assessed. It is an effective regional tool for determining the likely impacts of new irrigation development and, potentially, the effects of the historical development of irrigation. It has been peer reviewed and accredited by the Murray-Darling Basin Commission (MDBC) as fit for purpose in assessing impacts of new irrigation development resulting from interstate water trade (MDBC, 2005a). This accredited application of SIMPACT is known as SIMRAT in the protocols to Schedule C of the MDBC Basin Salinity Management Strategy as it defines a specific method for root zone drainage rate definition and certain output format requirements. The hydrological models in both SIMPACT and SIMRAT are however identical. As such, it is an appropriate tool for generating groundwater inflows to the floodplain which are then modelled with FIP to determine the resultant salinity impact on the floodplain. Figure 6 schematically represents the processes simulated in SIMPACT2.

Figure 6. Schematic representation of SIMPACT2. Section (a) represents the drainage estimation; Section (b) represents SIMPACT2 using drainage as input for simulating the recharge process (from Munday et al., 2004).
3 Floodplain Wetland ImPacts (FWIP) Model

3.1 Conceptual Model

The floodplains have been conceptualised in a simple cross sectional model, comprising a surface layer of Coonambidgal Clay overlying a layer of Monoman Sands (Figure 7). The highland area is represented by the unconfined Upper Loxton (Pliocene) Sands aquifer. Both the highland and floodplain are underlain by the Lower Loxton Sands, a relatively impermeable clayey sand formation. In the region downstream of Overland Corner, the water table beneath the highland is generally contained within the Murray Group limestone aquifer that underlies the Pliocene Sands.

Figure 7. Conceptual model of groundwater inputs to the floodplain and potential groundwater discharge pathways within the floodplain, wetland and river. Groundwater entering the river valley can be discharged as either seepage at the break of slope and/or evapotranspiration through the floodplain surface. Groundwater can also move into or out of the wetland or the river. Baseflow can be into the river if the river level is below the groundwater level between the wetland and the river, or out of the river if the river level is higher than the groundwater level between the wetland and the river (i.e. upstream of the nearest weir).

The arrows in Figure 7 represent groundwater flow directions and potential groundwater discharge sites. Groundwater flow in the Upper Loxton Sands (or Murray Group limestone in the region below Overland Corner) is a combination of irrigation recharge and regional groundwater flow. Groundwater from the highlands is discharged as either seepage at the break of slope if the groundwater level is above the surface, evapotranspiration through the floodplain when the water table is within the evapotranspiration extinction depth (vegetation rooting depth), or into the wetland or river. The groundwater can also be recharged by surface water from the wetland or river, depending on water levels and wetland hydraulic conductivity. So, water can flow from the groundwater into the wetland or river, i.e. discharge, or from the wetland or river into the groundwater, i.e. recharge.

Predictions of groundwater discharge fluxes as seepage at the base of slope, evapotranspiration across the floodplain and into the wetlands were used to assess the potential salinisation risk from the combinations of floodplain width, river height, aquifer
parameters and groundwater inflows. Because the floodplain groundwater is naturally saline, high rates of evapotranspiration and seepage result in floodplain salinisation and consequent decline in floodplain vegetation health. While a number of other factors such as clearing and coppicing of trees, grazing of livestock and feral animals, insect attack and parasite infestation can contribute to floodplain vegetation health decline, these are generally second-order effects compared with those of salinisation (Jolly, 1996).

3.2 Model Assumptions

The following assumptions are made:

1. groundwater flow within the floodplain is one-dimensional, under steady state conditions with no recharge on the floodplain, and the floodplain aquifer is homogenous, isotropic and in good hydraulic connection with the river; and

2. groundwater flow under the floodplain follows Darcy’s Law (1), where \( Q \) is the flux of groundwater through a unit width of floodplain \( [L^2 T^{-1}] \); \( K \) is the hydraulic conductivity of the aquifer \( [L T^{-1}] \); \( b \) is the aquifer thickness \( [L] \); and \( \frac{dh}{dx} \) is the groundwater hydraulic gradient, where \( h \) is the height of the groundwater above river level \( [L] \) and \( x \) is the distance from the edge of the river valley \( [L] \) to a maximum distance \( L \) at the river;

\[
Q = -Kb \frac{dh}{dx}; \quad (1)
\]

3. loss of groundwater through evapotranspiration, \( ET \ [L T^{-1}] \) can be approximated using the simple linear function described by (2) and (3); where \( a \) is the maximum rate of groundwater lost by evapotranspiration at the floodplain surface on an areal basis \( [L T^{-1}] \). This maximum groundwater evapotranspiration rate declines to zero at \( z_{ext} \) (extinction depth), which corresponds to the vegetation rooting depth; \( h_f \) is the height of the floodplain above river level \( [L] \); and \( z_{ext} \) is the evapotranspiration extinction depth \( [L] \), or rooting depth, below which there is no evapotranspiration.

\[
ET = a \left[ \frac{h - (h_f - z_{ext})}{z_{ext}} \right] \quad h > h_f - z_{ext}; \quad (2)
\]

\[
ET = 0 \quad h \leq h_f - z_{ext}; \quad (3)
\]

4. a sharp cliff and a flat floodplain characterise the shape of the river valley; and

5. the wetland is located at a distance \( x_w \ [L] \) from the break of slope (where \( 0 < x_w < L \)). Groundwater flow into or out of the wetland is controlled by the wetland leakage parameter \( \beta \ [L T^{-1}] \) and groundwater levels. Groundwater flow is calculated as the flux to/from the highland side and the flux to/from the river side of the wetland. The flux into or out of the wetland is the difference between these two fluxes.

3.3 Mathematical Description

The FWIP model uses the elevation of the surface water in the river and wetland, groundwater flux to the river valley and other model parameters to decide whether the floodplain water table is above or below the vegetation rooting depth (model extinction depth) at the edge of the river valley, at the wetland and at the river. It must also decide whether the floodplain water table is above the floodplain surface at the break of slope, i.e. seepage occurs. There are three possible water table levels at the edge of the river valley: (A) above the floodplain surface and seepage occurs, (B) above the vegetation rooting depth, but below the floodplain surface and evapotranspiration occurs, and (C) below the vegetation rooting depth and no evapotranspiration occurs. There are two possible water table levels at the wetland: (D) above the vegetation rooting depth and evapotranspiration occurs, and (E) below the vegetation rooting depth and no evapotranspiration occurs. Finally, there are two
possible water table levels at the river: (F) above the vegetation rooting depth and evapotranspiration occurs, and (G) below the vegetation rooting depth and no evapotranspiration occurs. This means that there are 12 possible combinations of floodplain water table levels at the edge of the river valley, at the wetland and at the river (Figure 8).

Figure 8. Schematic cross section showing the 12 different groundwater flow scenarios that are solved by the FWIP model. Groundwater levels within the floodplain are denoted by letters A to G: at the break of slope (A) above the floodplain surface resulting in seepage; (B) below the floodplain surface, but within the extinction depth; or (C) below the extinction depth; at the wetland (D) above the extinction depth; or (E) below the extinction depth; and at the river (F) above the extinction depth; or (G) below the extinction depth.

Where one part of the floodplain water table is above and another part is below the vegetation rooting depth, the model predicts the proportion of each section of the floodplain (i.e. the floodplain between the highland and the wetland, or between the wetland and the river) that has the floodplain water table above the vegetation rooting depth. The floodplain water table above the vegetation rooting depth indicates that evapotranspiration occurs, which is used by the FWIP model to signal that there is a risk of salinisation in that area.

The model also calculates the proportion of groundwater flowing into the River Murray valley that is discharged as seepage at the break of slope, evapotranspiration from the floodplain on the highland or river side of the wetland, and the amount of groundwater flowing into or out of the wetland and the river. The flux of groundwater to the river predicted by the model was compared to measured salt loads along the river as a means of constraining the FWIP model outputs.

The full mathematical description of the model is given in Appendix A. Note that the model does not simulate situations where there are significant inflows of groundwater to the floodplain aquifer from leakage from underlying confined regional aquifers.

### 3.4 GIS Implementation

The FWIP model was implemented using spatial data sets developed within the ESRI ArcGIS 8 GIS program using the mathematical solutions programmed in the Visual Basic language described in Appendix B. The GIS spatial datasets used to populate the division fields are described below. The second section describes the model testing datasets and the third section describes the calculation and interpretation of the model outputs.
3.4.1 Base Datasets

The base datasets describe the physical, geometric and aquifer properties for each division.

Floodplain Boundary

The extent of flood inundation of the 1956 flood was used to define the spatial extent of the floodplain and to identify the location of the break of slope at the edge of the river valley.

Floodplain Divisions

The floodplain was divided into 3011 divisions that were ~250 m wide at the edge of the river valley (refer Figure 3). The divisions were used to implement the analytical cross sectional FWIP model spatially. The input and output fields for the divisions are described in detail in Table B1 in Appendix B. The FWIP model extinction depth is the "apparent" groundwater depth at which capillary rise of saline groundwater to the surface driven by evapotranspiration is zero. The actual groundwater depth is somewhat deeper than this, as the analytical model assumes a linear relationship between evapotranspiration and groundwater depth and a flat floodplain surface, whereas in reality there can be significant variations in surface topography. The maximum transpiration rate of the vegetation and the soil limited evaporation rate, or rate of evapotranspiration was set to 0.0001 m d⁻¹.

Floodplain aquifer parameters are known to vary spatially, however there are little data on which to base a varying surface. Therefore, a constant floodplain aquifer thickness of 10 m was assumed, which represents the saturated thickness of the floodplain aquifer below the Coonambidgal Clay layer. Implicit in this assumption is that the groundwater that is influencing evapotranspiration and seepage in the floodplain moves through the upper 10 m of the floodplain aquifer. The horizontal hydraulic conductivity of the floodplain aquifer is likely to vary spatially, however there are no data on which to base a varying surface, so the commonly reported value of 10 m d⁻¹ was used.

Wetland Data

The DEH wetland database and permanent water dataset from the FIM were used to identify potential wetlands for the FWIP model. A process of consultation occurred where the wetland that had the best connection to the groundwater system and was most likely to intercept groundwater discharge was selected where there were many possible wetlands per division. The FIM was also used to determine which wetlands were permanent and which were ephemeral. Note that the FWIP model can only model a single wetland per division. However, provided the wetland that had the best connection to the groundwater system and most likely to receive groundwater discharge was chosen, this was considered appropriate. The distance from the highland edge to the wetland was calculated spatially. Where there was no wetland, this value was set to half the division length.

The wetland leakage parameter, 'beta' represents the hydraulic conductivity of the soil layer between the wetland and the groundwater multiplied by the width of the wetland along the division flowpath and by the thickness of the soil layer. This is known to vary spatially, however there are little data available. Therefore, as a result of the model testing a constant value of either 10 or 65 m d⁻¹ was assumed for divisions with wetlands. Where there was no wetland, this value was set to zero.

The FIM was used to calculate the height of the wetland surface water level above sea level. In wetlands that were not permanently flooded, the minimum elevation from the FIM was used to determine the deepest point in the wetland. Where there was no wetland, this value was set to the river level for that division. This was used to calculate the height of the wetland surface water level above (+'ve) or below (-'ve) the river level, or where there was no wetland this value was set to zero.
Floodplain ImPact Response Units (FIPRUs)

The divisions were aggregated into ~250 FIPRUs, which broadly represent the major floodplains of the lower River Murray in South Australia. FWIP divisions were separated into areas of wide and narrow floodplain based on a threshold width of 300 m that were then lumped together to form each FIPRU. These FIPRUs form the basis for the connection between the highland and the floodplain for models such as the Lower Murray Landscape Futures Project’s River Murray Corridor Systems Model.

Location Data

A number of other datasets were used in the model to assist in identifying the location of the impacts. These include towns, roads, Land and Water Management Plan areas, permanent water and wetlands.

Pre-Irrigation/Clearance Highland Groundwater Depth

DWLBC provided a contour map of the estimated groundwater depth surface prior to commencement of any irrigation and native vegetation clearing for the regional aquifers beneath the highland areas adjacent to the floodplain. As this was based on no measured data it has great uncertainty. This coverage was used to estimate the natural pre-irrigation/clearance inflows to the floodplain from the regional aquifers beneath the highland for each FIPRU.

Unconfined Highland Aquifer Transmissivity

The transmissivity coverage in SIMPACT (Miles et al., 2001) was used for the transmissivity of the unconfined regional highland aquifer (Loxton (Pliocene) Sands upstream of Overland Corner and Murray Group downstream of Overland Corner). This coverage was used to estimate the natural pre-irrigation/clearance inflows to the floodplain from the regional aquifers beneath the highland for each FIPRU.

River Levels

River levels at each kilometre interval along the river were obtained from the Flood Inundation Model for a river height at entitlement flow (Overton et al., 1999). The river heights were based on recorded and modelled backwater curves (Figure 9).

![Figure 9. Graph of river heights for entitlement flow, 100,000 ML d⁻¹ and the 1956 flood. The FWIP model uses the entitlement flow for river levels and the 100,000 ML d⁻¹ heights for floodplain edge height. The height of the floodplain above river level (h_f) is given by the difference between the height of the river level at 100,000 ML d⁻¹ and at entitlement flows.](image-url)
**Height of the Floodplain Edge**

The height of the floodplain at the edge of the river valley was determined from the river height of a 100,000 ML d⁻¹ flood. This value was used to determine the maximum groundwater elevation at the edge of the floodplain before seepage occurs and is compared to the river height to obtain $h_f$ for the analytical model. There are some problems in using these flood levels to determine the floodplain edge, as it will vary, however no actual elevations are available for this ‘break of slope’ edge. Recorded data of river height at kilometre markers from the mouth, and flow at the gauge were obtained from the Engineering and Water Supply (EWS) Department for a range of floods. As there were insufficient points to generate a relationship between flow and river height for a range of floods, it was necessary to use the EWS back water curves.

**Floodplain Surface Elevation**

The FWIP model assumes a flat floodplain surface. Therefore, the river height of a 100,000 ML d⁻¹ flood was used to define the model floodplain surface elevation.

### 3.4.2 Model Testing Datasets

The model testing datasets were used to constrain the input parameters and provide a ‘realistic’ test of the model outputs against independently measured values.

#### 3.4.2.1 Run-of-River Salinity Values

Run-of-river salinity values were obtained from DLWBC for various years including a complete ‘Lakes to the Border’ dataset for 2001 (Porter, 2001). The data recorded salt load into the river at a one-kilometre interval along the river. These data was linked to a spatial coverage of points at one-kilometre intervals to validate the spatial variability of salt load inputs. As discussed in Overton *et al.* (2003), the run-of-river data does not measure exactly where the inflows are emanating due to mixing processes in the river. For this reason, caution was needed when they were used to test the model predictions.

#### 3.4.2.2 Vegetation Health

Vegetation floristics and tree health maps for the entire floodplain in South Australia were developed by DEH based on field surveys carried out in 2002/2003. For the purpose of developing and testing FWIP these were used to determine for each floodplain division the proportion of dead trees, unhealthy trees, healthy trees, and halophytes. Tree health was taken from the first tree health code for each polygon (the DEH vegetation survey defined up to three vegetation floristic groups and tree health classes per mapped area). An area was defined as halophytes if the first floristic group was mapped as *Halosarcia*, *Sarcocornia*, *Pachycornia* or *Suaeda* species. Other non-tree and non-halophyte floristic groups were classed as not tree. These tree health classes were compared to the predicted FWIP and FRM risk classes as a means of evaluating the model outputs.

#### 3.4.2.3 Observed Seepage Areas

The location of areas where seepage was observed at the break in slope was recorded from field work and anecdotal evidence. This does not include areas where seepage occurs from perched water tables under irrigation areas such as Walkerie and Loxton. In these areas seepage can occur on the cliff face and have not been used for model testing as FWIP deals exclusively with seepage effects on the floodplain.

### 3.4.3 Model Outputs

#### 3.4.3.1 Salt load to the river

The ‘salt load to the river (tonnes d⁻¹)’ was calculated for each division and is the product of the groundwater flux to the river and the division salinity. In cases where the river level was above the floodplain water table at the river and there was groundwater flow from the river into the floodplain aquifer, this field was set to zero.
### 3.4.3.2 Salt load to the wetland
The ‘salt load to the wetland (tonnes d\(^{-1}\))’ field was calculated for each division and is the product of the groundwater flux into the wetland and the division salinity. In cases where the floodplain water table at the wetland was below the wetland surface and there was groundwater flow from the wetland into the floodplain aquifer, this field was set to zero.

### 3.4.3.3 Salt load to the river and wetlands
This field is the sum of the ‘salt load to the river (tonnes d\(^{-1}\))’ and the ‘salt load to the wetland (tonnes d\(^{-1}\))’ fields.

### 3.4.3.4 Seepage risk
The ‘% of modelled floodplain edge with seepage’ was calculated from the ‘length of modelled floodplain edge’ and ‘length of modelled floodplain edge with seepage (km)’, where the EDGE\(_L\) field is the width of the division at the edge of the river valley and a value greater than zero in the QS field indicates that seepage occurs.

### 3.4.3.5 Vegetation area at risk of salinisation
Each floodplain division was divided into three parts, the ‘highland side of the wetland’, the ‘wetland’ and the ‘river side of the wetland’. The vegetated area for each of these three parts was calculated based on the distance of the centroid of each vegetation polygon from the edge of the river valley relative to the distance of the centroid of the wetland polygon from the edge of the river valley. This gave an area of floodplain vegetation on the ‘highland side of the wetland’, in the wetland and on the ‘river side of the wetland’.

The model outputs were used to determine the proportion of vegetation on the ‘highland side of the wetland’ that had the water table within the rooting depth. As an example, if the water table was above the vegetation rooting depth at the edge of the floodplain and below the vegetation rooting depth at the wetland and the water table crossed the vegetation rooting depth at a point that is 40% of the distance between the edge of the river valley and the wetland, then 40% of the highland division area was at risk of salinisation (Figure 10). This means that the ‘vegetation area at salinity risk on the highland side of the wetland (ha)’ was equal to the product of the ‘vegetation area on the highland side of the wetland (ha)’ and 0.4.

![Figure 10. Schematic cross section showing an example of scenario BEF where the floodplain water table is above the vegetation rooting depth at the edge of the river valley (B), below the vegetation rooting depth in the wetland (E) and above the vegetation rooting depth at the river (F). The vegetation area at salinity risk on the highland side of the wetland and on the river side of the wetland are indicated by the thick red lines.](image-url)
The ‘wetland area at salinity risk (ha)’ was calculated from the ‘wetland area (ha)’ and whether there was groundwater flux from the floodplain aquifer into the wetland. Salinity risk to the wetland occurs when there is groundwater discharge into the wetland, i.e. negative groundwater flux.

The ‘vegetation area at salinity risk on the river side of the wetland (ha)’ was calculated from the proportion of the floodplain between the wetland and the river that had the water table within the vegetation rooting depth. For example, if the river is above the vegetation rooting depth and the water table is below the vegetation rooting depth at the wetland and the water table crosses the vegetation rooting depth at a point that is 60% of the distance between the wetland and the river, then 60% of the river portion of the division area is at risk of salinisation (Figure 10). This means that the ‘vegetation area at salinity risk on the river side of the wetland (ha)’ is equal to the product of the ‘vegetation area on the river side of the wetland (ha)’ and 0.6.

The ‘% of vegetation and wetlands at salinity risk’ was calculated from the sum of the ‘vegetation area at salinity risk on the highland side of the wetland (ha)’, ‘wetland area at salinity risk (ha)’ and ‘vegetation area at salinity risk on the river side of the wetland (ha)’ divided by the sum of the ‘vegetation area on the highland side of the wetland (ha)’, the ‘wetland area (ha)’ and the ‘vegetation area on the river side of the wetland (ha)’ or the ‘total vegetation area on the floodplain (ha)’. This represents the proportion of floodplain vegetation in the division where the water table was within the vegetation rooting depth.

3.5 SIMPACT2 Groundwater Inflows

As illustrated in Figure 6, SIMPACT2 is a standalone GIS-based modelling framework aimed at simulating changes in drainage below the root zone, time delays for recharge to the groundwater system and discharge to the river valley (discharge edge), which may result from a change in land use. It allows the calculation of the impacts from a range of root zone drainage scenarios (e.g. native vegetation to dryland agriculture, native vegetation to irrigation, dryland agriculture to irrigation, change in irrigation efficiency etc).

For use in providing the groundwater inflows to the floodplain for the FWIP model, specific root zone drainage scenarios were required to calculate increases in groundwater flow to the floodplain resulting firstly from the ‘legacy of history’ of existing irrigation, and secondly from a future irrigation development scenario, based on the ‘prior commitments’ the South Australian government have made to River Murray irrigators. Due to the large time delays between commencement of an irrigation development and the resultant inflow of groundwater to the floodplain, predictions of groundwater inflows to the floodplain were made at multiple reporting times, namely 2000 (representing current conditions), 2020, 2050 and 2100.

One of the outputs from SIMPACT2 runs was a series of grids describing total increase of flux resulting from the root zone drainage increase at each cell location. Some applications are concerned with solely aggregating these volumes and converting them to salt loads by applying relevant groundwater salinities. The FWIP model however is concerned with where along the discharge edge these increases occur, and aggregating the fluxes with reference to the floodplain divisions.

These two issues were addressed by:

1. Developing procedures to post process SIMPACT2 outputs in order to calculate the lateral distribution of groundwater flux increases and aggregate them to arrive at floodplain division inflows; and

2. Generating two spatially defined drainage scenarios a) ‘legacy of history’ and b) a future ‘prior commitment’ irrigation development scenario. The resulting flux increases were distributed laterally and aggregated to the FWIP divisions.
3.5.1 Lateral Distribution of SIMPACT2 Outputs for the FWIP Model

SIMPACT2 uses the Unit Response Equation (URE) to calculate the volumetric increase in groundwater discharge flux to the river valley over time from an increase in recharge resulting from a particular root zone drainage scenario in the highland. The location of the highland recharge source relative to the edge of the river valley is shown in Figure 11 (from Knight et al. 2005). The parameter ‘a’ was used to describe the distance between the highland recharge source and the edge of the river valley. Rassam et al. (2004) developed a modified form of the URE that laterally distributes the flux increases across the discharge edge, or the edge of the river valley. This was needed to determine which floodplain divisions in the FWIP model receive the discharge flux from a given root zone drainage scenario and to determine the magnitude of this flux over time.

Figure 11. Location of the URE modelled recharge point at a distance of ‘a’ perpendicular to the river. Reproduced from Figure 1, Knight et al. (2005).

This modified form of the URE shows that 50% of the flux occurs within ‘2a’ of the central discharge point (Figure 12). Where, the central discharge point is the closest point on the discharge edge to the highland recharge source and has a distance of ‘a’ from the discharge edge and ‘2a’ is twice the distance from the highland recharge source to the edge of the river valley.

Table 1 shows the cumulative percentage distributions of the flux relative to ‘a’, as derived from Figure 12. Note that ‘2a’ indicates a distance of ‘1a’ either side of the central discharge point. Because this project is considering drainage increases as far back as 15 km from the river, and the floodplain edge does not mimic an infinitely straight discharge edge (as assumed in the modified URE mathematics used to derive Figure 12), it was decided to limit the lateral influence of inflows to ‘6a’ from the central discharge point of any particular cell. This would account for 79% of the flux, so to maintain mass balance the remaining 21% that would report to the river at more than ‘6a’ away was proportionately allocated to within the ‘6a’ threshold (Final Value Used column in Table 1).
The Floodplain Risk Methodology (FRM)

Figure 12. Lateral flux distribution along the discharge edge separating the highland and the river valley as a function of distance from central discharge point. Reproduced from Rassam et al. (2004).

Table 1. Cumulative percentage distributions of the flux in relation to the distance from the central discharge point on the discharge edge, as derived from Figure 12. Also shown are the final values adopted for use in this project.

<table>
<thead>
<tr>
<th>Distance Along Discharge Edge</th>
<th>Cumulative % Flux to the Discharge Edge</th>
<th>Final Value Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a</td>
<td>50%</td>
<td>63%</td>
</tr>
<tr>
<td>4a</td>
<td>70%</td>
<td>88%</td>
</tr>
<tr>
<td>6a</td>
<td>79%</td>
<td>100%</td>
</tr>
<tr>
<td>8a</td>
<td>84%</td>
<td>–</td>
</tr>
<tr>
<td>10a</td>
<td>87%</td>
<td>–</td>
</tr>
<tr>
<td>12a</td>
<td>89%</td>
<td>–</td>
</tr>
<tr>
<td>14a</td>
<td>91%</td>
<td>–</td>
</tr>
<tr>
<td>16a</td>
<td>92%</td>
<td>–</td>
</tr>
<tr>
<td>18a</td>
<td>93%</td>
<td>–</td>
</tr>
<tr>
<td>20a</td>
<td>94%</td>
<td>–</td>
</tr>
<tr>
<td>&gt;20a</td>
<td>100%</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 13 shows graphically the final percentages used in the lateral distribution of the discharge flux induced by any particular cell. Radius 1 is analogous to ‘a’, and the concentric circles show how densified division points that lie on the discharge edge are used to identify divisions within each of the three distribution classes. The densified points associated with each division were important due to variations in division width which put some division centre points out of reach when they in fact were partially subject to inflows. Without the more numerous densified points, such divisions would have been deprived of their inflows as the centre point would be missed in a spatial overlay selection based on the circle.

Figure 13 also shows grid cell centroids output from SIMPACT2 that have discharge increases associated with them (flux2000r_pt in legend). It is these centroids’ flux values that are distributed via this method and then aggregated at the division centres for feeding...
into the FWIP model. This process is explained in more detail in Section 3.5.2 in relation to the methodology for accounting for ‘legacy of history’ inflows.

3.5.2 Legacy of History

To calculate inflows to the floodplain now and at future times, it is necessary to map the spread and timing of irrigation development along with the spread and timing of native vegetation clearance.

Vegetation clearance was defined specifically as clearance of native mallee vegetation communities. It is these communities that utilised virtually 100% of available rainfall. So when cleared and converted to dryland cropping, such areas were sources of increased root zone drainage. These areas were identified from polygons in Pre-European vegetation mapping (DEH, 2004) classed as mallee but not present as mallee in current native vegetation mapping (Faulkes and Gillen, 2000). Due to a lack of spatial information detailing the timing of vegetation clearance, a conservative assumption that all clearance occurred in 1920 was made.

Rates of increased root zone drainage under the cleared areas identified were sourced from a previous analysis that used relationships between root zone drainage under dryland farming systems and rainfall as well as soil texture (Cook et al., 2004). This was a spatially varying grid of the whole region indicating root zone drainage at each cell location.

The approximate era of irrigation commencement was defined for each irrigation area from a combination of local knowledge and historical documents. Several areas where selected for more intense date mapping from historical aerial photography. These areas include Moorook, Waikerie, Qualco, Murtho and Bookpurnong. Some of these were included in case study investigations during validation/accreditation stages of the SIMRAT project (MDBC, 2005a).

Maps showing both irrigation development over time and the extent of Mallee clearance are presented in Figures 14 to 16.

Root zone drainage rates under irrigated crops have changed over time with improvements in irrigation technology and management techniques. Table 2 shows the rates used for the different eras of irrigation development. Irrigation from the late 1800s to the 1970s was assigned root zone drainage of 300 mm yr⁻¹. In the 1980s irrigation was assigned 160 mm yr⁻¹, and ‘modern’ irrigation from 1990s to 2000s was assigned 120 mm yr⁻¹.
SIMPACT2 performs its assessments assuming a constant root zone drainage rate, so these rates including the clearance run (with its spatially varying drainage rate) were assumed to continue for duration of the assessment. In other words, all irrigation that started in the 1980s was assumed to have 160 mm yr\(^{-1}\) of drainage for 100+ years. The exception to this is the very old irrigation which was assumed to have improved from 300 mm yr\(^{-1}\) to 160 mm yr\(^{-1}\) in the 1980s.

**Table 2. Root zone drainage rates applied depending on when the action started. These rates are kept constant for the duration of the analysis.**

<table>
<thead>
<tr>
<th>Era of Action</th>
<th>Long Term Drainage Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880s – 1970s irrigation</td>
<td>300 mm yr(^{-1}) with reduction to 160 mm yr(^{-1}) after 1970</td>
</tr>
<tr>
<td>1980s irrigation</td>
<td>160 mm yr(^{-1})</td>
</tr>
<tr>
<td>1990s - 2000s irrigation</td>
<td>120 mm yr(^{-1})</td>
</tr>
<tr>
<td>1920 mallee clearance</td>
<td>1 – 16 mm yr(^{-1}) spatially varying</td>
</tr>
</tbody>
</table>
Figure 14. Map of irrigation development over time and the extent of Mallee clearance for the Border to Lock 3 reach.
Figure 15. Map of irrigation development over time and the extent of Mallee clearance for the Lock 3 to Lock 1 reach.
Figure 16. Map of irrigation development over time and the extent of Mallee clearance for the Lock 1 to Mannum reach.
Four SIMPACT2 runs were performed that modelled each of the above root zone drainage rates: ‘300 mm yr\(^{-1}\)’, ‘160 mm yr\(^{-1}\)’, ‘120 mm yr\(^{-1}\)’, and the ‘mallee clearance’ grid. In addition, a fifth run which modelled the decrease in root zone drainage from 300 to 160 mm yr\(^{-1}\) was carried out. Table 3 summarises these five runs in terms of the root zone drainage rates. It also summarises which groundwater layer was used for each run – pre 1980s runs used a pre-irrigation groundwater level, and post 1980s used the current groundwater level including irrigation induced mounds. These runs each produced a layer of flux increase values for each grid cell relative to the root zone drainage rate for each decade up to 100 years. These outputs form the base data for aggregation into inflows for the target dates.

Table 3. Summary of the five SIMPACT2 runs used to construct the ‘legacy of history’ inflows to the river valley from current irrigation.

<table>
<thead>
<tr>
<th>Years</th>
<th>Root Zone Drainage</th>
<th>Groundwater Layer</th>
<th>SIMPACT2 Run Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1880-1970</td>
<td>300 mm yr(^{-1})</td>
<td>pre-irrigation</td>
<td>1p</td>
</tr>
<tr>
<td></td>
<td></td>
<td>depth = 3 m</td>
<td>1o</td>
</tr>
<tr>
<td>1980</td>
<td>160 mm yr(^{-1})</td>
<td>pre-irrigation</td>
<td>2p</td>
</tr>
<tr>
<td></td>
<td></td>
<td>depth = 3 m</td>
<td>2o</td>
</tr>
<tr>
<td>1990 onwards</td>
<td>120 mm yr(^{-1})</td>
<td>2000 levels</td>
<td>3s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>depth = 3 m</td>
<td>3o</td>
</tr>
<tr>
<td>Pre 1980</td>
<td>from 300 mm yr(^{-1})</td>
<td>depth = 3 m</td>
<td>4o</td>
</tr>
<tr>
<td>1920 onwards</td>
<td>&lt;16 mm yr(^{-1})</td>
<td>2000 levels</td>
<td>5s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>depth = 3 m</td>
<td>5o</td>
</tr>
</tbody>
</table>

To generate inflows at 2000, 2020, 2050 and 2100, a matrix was developed to describe which results from which runs required aggregation for each era of irrigation or clearance (Table 4). One issue in this process is that the SIMPACT2 model can only predict 100 years out from the start of root zone drainage increase. So the matrix also needed to describe which eras of irrigation required a second grid to be added to reach the desired target date. This second grid was sourced from a run of the same root zone drainage that had been allocated a depth to groundwater of 3 m (Table 3). This was to simulate the fact that the soil profile had been ‘wet up’ and therefore any further root zone drainage would reach the water table without delay. These groundwater settings acted to remove the vertical timelag calculation from the SIMPACT2 runs.

To illustrate this aggregation process let’s assume an area had some irrigation that commenced in 1920 and some in 1980. To obtain 2000 inflows we would need to aggregate the 80 year output of the ‘300 mm yr\(^{-1}\)’ run (in grid cells where 1920 irrigation occurs) with the 20 year output of ‘160 mm yr\(^{-1}\)’ run (where 1980 irrigation occurs). To obtain the 2050 inflows we would need to aggregate the 100 year and the 30 year outputs from the ‘300 mm yr\(^{-1}\)’ run (in grid cells where 1920 irrigation occurs) with the 70 year output from the ‘160 mm yr\(^{-1}\)’ run (where 1980 irrigation occurs). A further complexity to this is the issue of reduction in root zone drainage for old irrigation. This would require the 30 year output from the ‘300 to 160 mm yr\(^{-1}\)’ run to be subtracted from the 2000 inflows described above, and the corresponding 80 year output to be subtracted from the 2050 inflows.

Using the matrix described in Table 4, the cells corresponding to irrigation or clearance for each date were aggregated to produce a single grid of inflows at each of the target dates of 2000, 2020, 2050 and 2100. Each of these inflow grids were then processed using the lateral distribution algorithm described in Section 3.5.1. Figures 17 to 22 provide a graphical illustration of this process based around the Loxton irrigation area for the target date of 2000.
Table 4. Matrix describing the aggregation of SIMPACT2 runs required for each era of irrigation or clearance to provide the fluxes to the river valley for each of the reporting times (2000, 2020, 2050 and 2100).

<table>
<thead>
<tr>
<th>Irrigation Era Decades Required (Run Name)</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
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<td>100 (1p) + 100 (1o) + 100 (1o) + 20 (1o)</td>
</tr>
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<td>130</td>
<td>180</td>
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The Floodplain Risk Methodology (FRM)

Figure 17. Step 1 – irrigation era and clearance mapping are converted into mutually exclusive layers of grid cells.

Figure 18. Step 2 – cells containing irrigation commencing in 1940s are used to extract 60 year flux values from the ‘300mm yr⁻¹’ run.

Figure 19. Step 3 – the same cells are used to extract 20 year flux values (negative) from the ‘300mm yr⁻¹-160mm yr⁻¹’ run to account for the improvement in efficiency in the 20 years prior to 2000.

Figure 20. Step 4 - Cells containing areas of Mallee cleared in 1920s are used to extract 80 year flux values from the ‘clearance’ run.
3.6 Model Implementation

3.6.1 Development of Pre-Irrigation/Clearance Groundwater Inflows

As described above SIMPACT2 predicts the groundwater flux to the floodplain that occurs as a result of irrigation development and clearing of native vegetation for dryland agriculture. In addition to these are the natural inflows that occur as a result of the lower River Murray being one of the main discharge locations for the saline regional groundwater systems of the western Murray Basin. The natural pre-irrigation/clearance inflows to the floodplain from the regional aquifers beneath the highland were calculated for each FIPRU using the unconfined highland aquifer transmissivity and the interpolated pre-irrigation/clearance highland groundwater surface using Darcy's Law. To calculate the groundwater gradient into the floodplain, the river level was set to the river height at entitlement flow. Because of the great uncertainty in these approximate estimates they were further adjusted during model testing based on estimates from previous studies such as the Regional Saline Water Disposal Strategy (AWE, 2003a) and ensuring that no seepage areas were predicted. The final adopted pre-irrigation/clearing groundwater fluxes to the river valley are summarised by Land and Water Management Plan (LWMP) area in Figure 23 (along with final adopted values of the total inflows for the years 2000, 2020, 2050 and 2100 as discussed below).
Figure 23. Summary by LWMP area of the final adopted pre-irrigation/clearance and total groundwater fluxes to the river valley for the years 2000, 2020, 2050 and 2100.

3.6.2 Floodplain Inflows for 2000 and Comparison to Other Studies

The total inflows at the year 2000 to each floodplain division were calculated by adding the pre-irrigation/clearance groundwater fluxes to the irrigation-induced fluxes predicted by SIMPACT2 for the year 2000. In the case of areas with salt interception schemes, the total current inflows were reduced in relation to the volume of groundwater intercepted at 2000. The total inflows were then summarised into their respective Land and Water Management Planning (LWMP) regions to allow comparison with other reported inflow fluxes and salt loads. Because of the uncertainty in the pre-irrigation/clearance fluxes these were adjusted in order to match FWIP predictions with observed seepage areas and to get within the ‘ballpark’ of previously reported fluxes and salt loads.

In most LWMP areas the SIMPACT2 fluxes for the year 2000 were not altered. However there were three areas where the SIMPACT2 predicted fluxes appeared unrealistic and therefore required some adjustment. Firstly, they were reduced by 5 times in the Ral Ral LWMP area and by 3 times in the Berri-Barmera LWMP area as the predicted salt loads were far in excess of what was observed from Run-of-River salinity surveys for the period 1998-2003 and other reported values. It is thought that this was because these areas have Comprehensive Drainage Schemes and so the root zone drainage rates used in SIMPACT2 are probably overestimates. While outside the scope of this project, it is clear that further investigation of this issue is needed. In the Pyap-Kingston LWMP area the groundwater fluxes to the river valley were reduced by 2 times to better match the Run-of-River salinity surveys and other reported values. The reason for the overestimate in this area is unclear but it may be because a reasonable proportion of the irrigation in this LWMP is very old and the estimated root zone drainage rates used in SIMPACT2 are too high for these areas. Further investigation is required.

The total groundwater fluxes to the river valley were also adjusted for the three currently operating salt interception schemes in the Lock 2 to Lock 3 reach based on the recent detailed MODFLOW modelling of these schemes by Middlemis et al. (2004). In the year 2000, the Woolpunda salt interception scheme was predicted to be intercepting approximately 90% of the total inflows and so the total groundwater fluxes to the river valley for 2000 were reduced by 90% in the Woolpunda LWMP area. Similarly, in the year 2000 the Waikerie salt interception scheme was predicted to be intercepting approximately 51% of the total inflows and so the total groundwater fluxes to the river valley for 2000 were reduced by 51% in the Waikerie LWMP area. The Qualco-Sunlands salt interception scheme had not
yet commenced operation in 2000 and so no adjustment was made to the total groundwater fluxes to the river valley for 2000 in the Qualco-Sunlands LWMP area.

The final adopted groundwater fluxes to the river valley at the year 2000 are displayed spatially in Figures 24 to 26, and are summarised by LWMP area in Figure 23. These figures also show the values for the years 2020, 2050 and 2100 to highlight the changes in fluxes with time. Using these fluxes, and the SIMPACT2 highland groundwater salinities, the salt loads to the river valley were calculated and these are summarised by LWMP area for all of the reporting times in Figure 27.

These final adopted groundwater fluxes to the river valley were the primary input data for the FWIP model. While the primary purpose of the FWIP model was to predict floodplain and wetland salinity risk it also predicted the groundwater fluxes to the river. These were converted to approximate salt loads to the river using the groundwater salinities in SIMPACT2. While river salt load prediction was not the primary purpose of the model, it was a useful test of the accuracy of the groundwater inflows and the resultant model predictions. When compared to the Run-of-River salinity surveys for the period 1998-2004 (Figure 28), the patterns of the predicted cumulative salt load to the river were reasonable but the absolute values were somewhat high and exceeded the Standard Error (SE) range of the Run-of-River values. They were also slightly higher than the average salt loads for the same period that were predicted by the MSM–BIGMOD model (MDBC, 2005b; Figure 29).

In converting the predictions of groundwater fluxes to the river to salt loads, lack of salinity data for the floodplain aquifer meant that the groundwater salinities used in SIMPACT2 were adopted. However, during the inflow flux adjustment process it was observed that in some areas the groundwater salinity values in SIMPACT2 were higher than those observed in some local piezometers. If the average observed salinity in monitoring piezometers for each LWMP was used, then the predicted cumulative salt load was close to the upper SE of the Run-of-River surveys (Figure 28). For consistency we have used the SIMPACT2 values. However, it is clear that further work outside of this project is required to review the SIMPACT2 salinities in light of new drilling that has been carried out since the salinity coverages were constructed for the original version of SIMPACT (Miles et al., 2001). In spite of these concerns it is important to note that the FWIP model predicted fluxes of water through the floodplain and not salt loads per se, and so the comparison with measured salt loads was only carried out to assist in assessing the accuracy of the groundwater inflows. A summary by LWMP area of the comparison between the fluxes and salt loads to the river valley for the year 2000 used in the FWIP model and those from previous studies is shown in Table 5.
Figure 24. Final adopted groundwater fluxes to the river valley in the Chowilla to Lock 3 reach for the years 2000, 2020, 2050 and 2100.
Figure 25. Final adopted groundwater fluxes to the river valley in the Lock 3 to Lock 1 reach for the years 2000, 2020, 2050 and 2100.
Figure 26. Final adopted groundwater fluxes to the river valley in the Lock 1 to Mannum reach for the years 2000, 2020, 2050 and 2100.
Figure 27. Summary by LWMP area of the salt load to the river valley for the years 2000, 2020, 2050 and 2100 based on the final adopted pre-irrigation/clearance and total groundwater fluxes to the river valley and the SIMPACT2 highland groundwater salinities.

Figure 28. Cumulative salt loads to the river, and river plus wetlands, predicted by FWIP for the year 2000 and the average Run-of-River salt loads for 1998-2004 (including the Standard Errors, SE). Note that there are no Run-of-River data for the Lock 1 to Mannum reach (data provided by Barry Porter, DWLBC, Berri).
Figure 29. Comparison between FWIP salt load predictions for year 2000 and those from the MSM–BIGMOD model (MDBC, 2005b) and the average Run-of-River data for the period 1998-2004. Note that the MSM–BIGMOD model (MDBC, 2005b) predictions are for Lock 9 to Murray Bridge, whereas the FWIP predictions are from the Border (between Lock 6 and Lock 7) and Mannum (data provided by Barry Porter, DWLBC, Berri).
### Table 5. Summary by LWMP area of the final adopted FWIP pre-irrigation/clearing and year 2000 inflows and salt loads to the river valley and predicted salt loads to the river and wetlands. Data from previous studies are presented for comparison.

<table>
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<th>Pre-Irrigation and clearing inflows</th>
<th>Pre-Irrigation and clearing salt loads to river valley</th>
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<td>9,500.0</td>
<td>190.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smith and Watkins 1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riverland Norwest</td>
<td>Overton et al. 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FWIP 2000</td>
<td>1,764.3</td>
<td>25.4</td>
<td>2,445.8</td>
<td>32.2</td>
<td>31.2</td>
</tr>
<tr>
<td></td>
<td>AWE 2003a (inflows at 2008)</td>
<td>4,854.2</td>
<td>63.0</td>
<td>8,052.0</td>
<td>82.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Morgan-Tailem Bend model (Wei Yan, DWLBC, pers. comm.)</td>
<td></td>
<td></td>
<td>1,319.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taylorville North</td>
<td>Overton et al. 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FWIP 2000</td>
<td>388.0</td>
<td>6.6</td>
<td>5,121.3</td>
<td>87.9</td>
<td>87.8</td>
</tr>
<tr>
<td></td>
<td>AWE 2003a (inflows at 2008)</td>
<td>446.3</td>
<td>16.0</td>
<td>3,857.6</td>
<td>78.0</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>AWE 2001c (Glenforslan and alluvium)</td>
<td></td>
<td></td>
<td>5,995.0</td>
<td>59.6</td>
<td></td>
</tr>
<tr>
<td>Waikerie</td>
<td>Overton et al. 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FWIP 2000</td>
<td>380.5</td>
<td>5.7</td>
<td>3,325.2</td>
<td>50.7</td>
<td>50.6</td>
</tr>
<tr>
<td></td>
<td>AWE 2003a (inflows at 2008)</td>
<td>1,878.2</td>
<td>20.0</td>
<td>4,210.2</td>
<td>23.0</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>Smith and Watkins 1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AWE 2000 (bore pumping volumes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middlesim et al. 2004 (includes SIS)</td>
<td></td>
<td></td>
<td>13,824.0</td>
<td>180.0</td>
<td>70-90 t/d intercepted</td>
</tr>
<tr>
<td>Woolpunda</td>
<td>Overton et al. 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FWIP 2000</td>
<td>1,014.6</td>
<td>360.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AWE 2003a (inflows at 2008)</td>
<td>9,894.6</td>
<td>208.0</td>
<td>12,887.1</td>
<td>37.0</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>Smith and Watkins 1993</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middlesim et al. 2004 (includes SIS)</td>
<td></td>
<td></td>
<td>5,357.0</td>
<td>100.4</td>
<td>100-120 t/d intercepted</td>
</tr>
</tbody>
</table>

### 3.6.3 Floodplain Inflows for 2020, 2050, 2100

As was the case for the SIMPACT2 predictions for the year 2000, the SIMPACT2 fluxes into the river valley for 2020, 2050 and 2100 were reduced by 5 times in the Ral Ral LWMP area, by 3 times in the Berri-Barmera LWMP area and by 2 times in the Pyap-Kingston LWMP area.

The total groundwater fluxes to the river valley at 2020, 2050 and 2100 were also adjusted for the four operating salt interception schemes in the Lock 2 to Lock 3 reach based on the predictions of Middlesim et al. (2004). In the years 2020, 2050 and 2100 the Woolpunda salt interception scheme was predicted to be intercepting approximately 90%, 92% and 93% of the total inflows respectively, and so the total groundwater fluxes to the river valley for each of those years were reduced by 90%, 92% and 93% in the Woolpunda LWMP area. Similarly, in the years 2020, 2050 and 2100 the Waikerie and part of the Waikerie 2A salt interception schemes was predicted to be intercepting approximately 69%, 79% and 78% of the total inflows respectively, and so the total groundwater fluxes to the river valley for those years were reduced by 69%, 79% and 78% in the Waikerie LWMP area. In the years 2020, 2050 and 2100 the Qualco-Sunlands and part of the Waikerie 2A salt interception schemes was predicted to be intercepting approximately 30%, 36% and 39% of the total inflows respectively, and so the total groundwater fluxes to the river valley for each of those years were reduced by 30%, 36% and 39% in the Woolpunda LWMP area.
The Floodplain Risk Methodology (FRM)

The final adopted groundwater fluxes to the river valley at the years 2020, 2050 and 2100 are displayed spatially in Figures 24 to 26, and are summarised by LWMP area in Figure 23. Using these fluxes, and the SIMPACT2 highland groundwater salinities, the salt loads to the river valley at the years 2020, 2050 and 2100 were calculated and these are summarised by LWMP area in Figure 27.

3.6.4 Predictions for Current Irrigation with Legacy of History

Predictions of the floodplain salinisation and seepage risk areas under current irrigation with ‘legacy of history’ for each of the reporting times are shown spatially in Figures 30 to 32. The salinisation risk is defined as the percentage of the division area predicted to have groundwater discharge by evapotranspiration occurring. A summary of the FWIP model predictions for the whole of the study area of salinisation and seepage risk and salt loads at each of the reporting times is given in Table 6. A summary by LWMP area of the comparison between the salt loads to the river and wetlands for the year 2000 predicted by the FWIP model and those from previous studies is shown in Table 5 in Section 3.6.2.

The predictions suggest that there are still very large increases in groundwater inflow to the river valley to come from current irrigation due to the ‘legacy of history’. Between 2000 and 2100 the inflows are predicted to increase by 76,830 m$^3$ d$^{-1}$ (102%). Not surprisingly, these very large increases in inflow are predicted to result in significant impacts on the floodplain, wetlands and the river. The area of vegetation and wetlands at risk of salinisation at 2100 is predicted to increase by 2,889 ha (9.1%) from that in 2000. The impacts are very much greater in terms of seepage risk with a predicted 70 km (166.7%) increase in the edge of the modelled floodplain with seepage between 2000 and 2100. Moreover, there is also a very significant impact in terms of salt loads to the river and wetlands, with an increase of 977 tonnes d$^{-1}$ (82.4%) predicted between 2000 and 2100. The location of the FWIP salinisation risk areas upstream of the nearest weir and adjacent to existing irrigation areas suggest that these floodplains have limited capacity to discharge more water by evapotranspiration as the groundwater is within the vegetation rooting depth in many of these areas. Therefore, the majority of the additional groundwater inflows that occur between 2000 and 2100 were predicted to be discharged as seepage and as groundwater inflows to the river and wetlands.

Table 6. Summary of FWIP predictions for the years 2000, 2020, 2050 and 2100 for current irrigation and clearing with ‘legacy of history’.

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater inflows to the river valley (m$^3$ d$^{-1}$)</td>
<td>75,444</td>
<td>83,112</td>
<td>108,017</td>
<td>152,274</td>
</tr>
<tr>
<td>Salt load to river (tonnes d$^{-1}$)</td>
<td>869</td>
<td>943</td>
<td>1,235</td>
<td>1,678</td>
</tr>
<tr>
<td>Salt load to wetlands (tonnes d$^{-1}$)</td>
<td>317</td>
<td>336</td>
<td>390</td>
<td>486</td>
</tr>
<tr>
<td>Salt load to river and wetlands (tonnes d$^{-1}$)</td>
<td>1,186</td>
<td>1,279</td>
<td>1,625</td>
<td>2,163</td>
</tr>
<tr>
<td>Length of modelled floodplain edge with seepage (km)</td>
<td>42</td>
<td>46</td>
<td>86</td>
<td>112</td>
</tr>
<tr>
<td>Total length of edge of modelled floodplain (km)</td>
<td>957</td>
<td>957</td>
<td>957</td>
<td>957</td>
</tr>
<tr>
<td>Modelled floodplain edge with seepage</td>
<td>4.4%</td>
<td>4.8%</td>
<td>9.0%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on highland side of wetland (ha)</td>
<td>9,456</td>
<td>9,606</td>
<td>9,988</td>
<td>10,454</td>
</tr>
<tr>
<td>Wetland area at salinity risk (ha)</td>
<td>9,644</td>
<td>9,669</td>
<td>9,688</td>
<td>9,702</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on river side of wetland (ha)</td>
<td>12,427</td>
<td>12,732</td>
<td>13,195</td>
<td>14,259</td>
</tr>
<tr>
<td>Total vegetation area on floodplain (ha)</td>
<td>87,742</td>
<td>87,742</td>
<td>87,742</td>
<td>87,742</td>
</tr>
<tr>
<td>Vegetation and wetlands at salinity risk</td>
<td>35.9%</td>
<td>36.5%</td>
<td>37.5%</td>
<td>39.2%</td>
</tr>
</tbody>
</table>
Figure 30. Predictions of the floodplain salinisation and seepage risk areas under current irrigation with ‘legacy of history’ in the Chowilla to Lock 3 reach for the years 2000, 2020, 2050 and 2100.
Figure 31. Predictions of the floodplain salinisation and seepage risk areas under current irrigation with ‘legacy of history’ in the Lock 3 to Lock 1 reach for the years 2000, 2020, 2050 and 2100.
Figure 32. Predictions of the floodplain salinisation and seepage risk areas under current irrigation with ‘legacy of history’ in the Lock 1 to Mannum reach for the years 2000, 2020, 2050 and 2100.
3.6.5 Validation of FWIP salinisation and seepage risk predictions

The distribution of FWIP salinisation risk and vegetation classes between the highland side of the wetland, the wetland and the river side of the wetland is shown in Table 7. Over half of the floodplain vegetation was located on the river side of the wetland (62%), while a quarter of the vegetation was located on the highland side of the wetland, and the wetlands contained only 13% of the floodplain vegetation. Table 7 shows that the vegetation on the highland side of the wetland was a mixture of healthy and unhealthy trees, halophytes and other vegetation, where most of the ‘other vegetation’ was chenopods and lignum. Not surprisingly, the vegetation in the wetland was predominantly herbaceous / wetland species, with some halophytes and few trees. The vegetation on the river side of the wetland was a mixture of healthy and unhealthy trees, some halophytes and other vegetation, where the ‘other vegetation’ was mostly lignum (48%) with chenopods and herbaceous / wetland species.

Table 7. Summary of FWIP predictions for the year 2000 for current irrigation and clearing with ‘legacy of history’ and the distribution of floodplain vegetation on the highland side of the wetland, in the wetland and on the river side of the wetland.

<table>
<thead>
<tr>
<th>Floodplain vegetation</th>
<th>Highland side of the wetland</th>
<th>Wetland</th>
<th>River side of the wetland</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy trees (ha)</td>
<td>3,927</td>
<td>126</td>
<td>13,916</td>
<td>17,969</td>
</tr>
<tr>
<td>Unhealthy trees (ha)</td>
<td>5,762</td>
<td>157</td>
<td>16,119</td>
<td>22,038</td>
</tr>
<tr>
<td>Dead trees (ha)</td>
<td>718</td>
<td>126</td>
<td>1,716</td>
<td>2,560</td>
</tr>
<tr>
<td>Halophytes (ha)</td>
<td>5,092</td>
<td>734</td>
<td>5,904</td>
<td>11,730</td>
</tr>
<tr>
<td>Other vegetation (ha)</td>
<td>6,175</td>
<td>10,338</td>
<td>16,931</td>
<td>33,444</td>
</tr>
<tr>
<td>% chenopods</td>
<td>50%</td>
<td>0%</td>
<td>31%</td>
<td>25%</td>
</tr>
<tr>
<td>% lignum</td>
<td>40%</td>
<td>1%</td>
<td>48%</td>
<td>31%</td>
</tr>
<tr>
<td>% herbaceous / wetland species</td>
<td>10%</td>
<td>99%</td>
<td>21%</td>
<td>44%</td>
</tr>
<tr>
<td>Healthy trees (% area)</td>
<td>18%</td>
<td>1%</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>Unhealthy trees (% area)</td>
<td>27%</td>
<td>1%</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>Dead trees (% area)</td>
<td>3%</td>
<td>1%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Halophytes (% area)</td>
<td>23%</td>
<td>6%</td>
<td>11%</td>
<td>13%</td>
</tr>
<tr>
<td>Other vegetation (% area)</td>
<td>28%</td>
<td>90%</td>
<td>31%</td>
<td>38%</td>
</tr>
</tbody>
</table>

When comparing the floodplain vegetation on either side of the wetland, there were an additional 20,000 ha of healthy and unhealthy trees on the river side of the wetland than on the highland side of the wetland. There were also an additional 1,000 ha of dead trees on the river side of the wetland, but the proportion of dead trees is the same for both sides of the wetland. Approximately 30% of the highland and river sides of the wetland were covered by other vegetation. However, the types of ‘other vegetation’ on either side of the wetland differ. On the highland side of the wetland most of the ‘other vegetation’ was chenopods (50%) and lignum (40%), whereas on the river side of the wetland the floodplain vegetation was predominantly lignum (48%), followed by chenopods (31%) and herbaceous / wetland species (21%).

Table 7 also shows the distribution of high and low FWIP model salinisation risk for the year 2000 for current irrigation and clearing with ‘legacy of history’. It shows that most of the
floodplain vegetation on the highland side of the wetland (44%) and in the wetlands (84%) was predicted to have high FWIP salinisation risk, whereas only 23% of the vegetation on the river side of the wetland was predicted to have high FWIP salinisation risk.

As a test of whether the FWIP model predictions were realistic, the proportion of areas with high FWIP salinisation risk was compared to the proportion of floodplain vegetation that is indicative of salinisation. Indicators of salinisation are unhealthy trees, dead trees and halophytes. On the highland side of the wetland, 53% of the floodplain vegetation was indicative of salinisation, which was comparable to the 44% of the floodplain area that was predicted to have high FWIP salinisation risk on the highland side of the wetland. The dominance of the herbaceous/wetland species in the other vegetation class (90%) in the wetlands was at odds with the high FWIP salinisation risk for 84% of the wetland vegetation. However, the FWIP model does not take into account the benefits of flooding for wetland vegetation species. On the river side of the wetland, 44% of the vegetation was indicative of salinisation, which was comparable to the prediction that 23% of the river side of the wetland was classed as having high FWIP salinisation risk.

Overall, the FWIP model predicted that 36% of the floodplain vegetation was at high FWIP salinisation risk, which was comparable to the 41% of the DEH vegetation mapping being classed as unhealthy trees, dead trees or halophytes. These three classes of vegetation are indicative of floodplain salinisation. The highland side of the wetland contained a greater proportion (53% c.f. 44% on the river side of the wetland) of floodplain vegetation that was indicative of salinisation. This was comparable to the pattern of FWIP model salinisation risk, where 44% of the highland side of the wetland was at high FWIP salinisation risk compared to 23% of the river side of the wetland. Most of the wetlands were predicted to have a high FWIP salinisation risk, whereas the dominant vegetation in the wetlands was herbaceous/wetland species, which is indicative of low salinisation. It is likely that the discrepancy between wetland vegetation classes and FWIP salinisation risk in the wetlands was related to flooding, which was not included in the FWIP model. There was not a comprehensive dataset to compare the location of observed seepage areas to those that were predicted. However, many of the predicted seepage areas were adjacent to the irrigation areas and appear to have been correctly predicted.

### 3.6.6 Validation of FWIP model extinction depth

The FWIP model extinction depth was varied between 1.5 m and 3.0 m depth to test the effect on predictions of salt loads, seepage areas and vegetation at salinity risk from groundwater discharge. Smaller and larger FWIP model extinction depths were not used because the model became mathematically unstable and they were considered to be unrealistic. The results of this sensitivity analysis are summarised in Table 8.

<table>
<thead>
<tr>
<th>Model Extinction Depth (m)</th>
<th>1.5 m</th>
<th>2.0 m</th>
<th>2.5 m</th>
<th>3.0 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater inflows to the river valley (m³ d⁻¹)</td>
<td>75,444</td>
<td>75,444</td>
<td>75,444</td>
<td>75,444</td>
</tr>
<tr>
<td>Salt load to river (tonnes d⁻¹)</td>
<td>917</td>
<td>869</td>
<td>819</td>
<td>785</td>
</tr>
<tr>
<td>Salt load to wetlands (tonnes d⁻¹)</td>
<td>339</td>
<td>317</td>
<td>302</td>
<td>304</td>
</tr>
<tr>
<td>Salt load to river and wetlands (tonnes d⁻¹)</td>
<td>1,256</td>
<td>1,186</td>
<td>1,121</td>
<td>1,089</td>
</tr>
<tr>
<td>Length of modelled floodplain edge with seepage (km)</td>
<td>44</td>
<td>42</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>Total length of edge of modelled floodplain (km)</td>
<td>957</td>
<td>957</td>
<td>957</td>
<td>957</td>
</tr>
<tr>
<td>Modelled floodplain edge with seepage</td>
<td>4.6%</td>
<td>4.4%</td>
<td>3.7%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on highland side of wetland (ha)</td>
<td>6,755</td>
<td>9,456</td>
<td>11,719</td>
<td>15,098</td>
</tr>
<tr>
<td>Wetland area at salinity risk (ha)</td>
<td>9,670</td>
<td>9,644</td>
<td>9,608</td>
<td>9,548</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on river side of wetland (ha)</td>
<td>4,856</td>
<td>12,427</td>
<td>20,500</td>
<td>29,462</td>
</tr>
<tr>
<td>Total vegetation area on floodplain (ha)</td>
<td>87,742</td>
<td>87,742</td>
<td>87,742</td>
<td>87,742</td>
</tr>
<tr>
<td>% Vegetation and wetlands at high FWIP salinisation risk</td>
<td>24.3%</td>
<td>35.9%</td>
<td>47.7%</td>
<td>61.7%</td>
</tr>
</tbody>
</table>
Using the current (2000) groundwater inflows to the river valley and changing the model extinction depth reduced model predictions of salt loads to the river and wetlands from a maximum of 1,256 tonnes d\(^{-1}\) when the model extinction depth was 1.5 m to 1,089 tonnes d\(^{-1}\) when the model extinction depth was 3.0 m. This reduction in salt loads was matched by an increase in the proportion of vegetation and wetlands at high FWIP salinisation risk, which increased from 24.3% when the model extinction depth was 1.5 m to 61.7% when the model extinction depth was 3.0 m. When the model extinction depth was small (i.e. 1.5 m deep), a greater proportion of the groundwater inflows are transmitted to the river and wetlands, resulting in a larger salt load and smaller proportion of vegetation and wetlands at high FWIP salinisation risk. The opposite occurs when the model extinction depth is large (i.e. 3.0 m deep), where a greater proportion of the groundwater inflows were discharged as evapotranspiration through the floodplain surface, resulting in a smaller salt load and a greater proportion of vegetation and wetlands at high FWIP salinisation risk.

A model extinction depth of 2.0 m was found to give the best predictions of salt loads to the river and wetlands and the proportion of vegetation and wetlands at high FWIP salinisation risk in comparison with available validation data for current groundwater inflows and other specified model parameters.
4 Floodplain Risk Methodology (FRM)

The FWIP model was able to predict the impacts of current irrigation, including the future impacts from ‘legacy of history’, based on the inflows to the river valley predicted by SIMPACT2. The FWIP model predictions that 36% of the floodplain vegetation was at high FWIP salinisation risk were comparable to the 41% of the vegetation mapping being indicative of floodplain salinisation. The model was also able to separate the salinisation risk between the highland and river sides of the wetland, where the highland side of the wetland was found to have a greater proportion of area at high FWIP salinisation risk, which was reflected in the floodplain vegetation mapping. However, the FWIP model did not include the benefits of flooding. This was evident in the discrepancy between wetland vegetation classes and FWIP salinisation risk in the wetlands, where most of the wetlands were predicted to have a high FWIP salinisation risk, but the dominant vegetation in the wetlands was herbaceous / wetland species, which is not indicative of floodplain salinisation.

In response to this limitation, the floodplain risk methodology was developed to assess the risks of irrigation development, river regulation and benefits of flooding to floodplain vegetation at the scale of the whole South Australian floodplain. At this scale, the limited groundwater and soil data meant that relatively simple analytical and empirical methodologies were necessary, rather than the data intensive floodplain models such as WAVES and WINDS (Overton and Jolly, 2004) or MODFLOW-2000 (Doble, 2004). Therefore, data from the DEH Vegetation Mapping, FWIP and FIM models were combined to form the Floodplain Risk Methodology.

An attempt was made to develop a broadscale version of the WINDS model using the mapped vegetation polygons. We tried to use a process based approach, where the rate of groundwater discharge calculated by the FWIP model for the highland, wetland and river portions of each floodplain division was ‘balanced’ by recharge from floods calculated from the area weighted flooding frequency of the vegetation polygon and a uniform soil hydraulic conductivity. However, after the initial attempts could not reproduce the patterns of tree health that had been mapped and modelled by WINDS (Overton and Jolly, 2004) for the Chowilla floodplain, the sensitivity of the WINDS model to soil parameters was tested. It was found that the WINDS model was sensitive to the spatial distribution of soil parameters and was unable to match the patterns of observed tree health when a single value was used for soil hydraulic conductivity. This lead to the development of a simpler method for combining the risks of salinisation and benefits of flooding as described below.

4.1 Integrated Use of FWIP and FIM

The Floodplain Risk Methodology is a process for combining the outputs of FWIP and FIM (Figure 33) to identify floodplain areas at risk of salinisation from irrigation development and river regulation, and where they may benefit from periodic flooding and weir pool manipulation.
The first step in the development of the FRM was to divide the floodplain into smaller units. The vegetation polygons from the vegetation floristic and tree health mapping of the River Murray floodplain in South Australia (DEH, 2004) and the floodplain vegetation mapping from the NSW side of the Chowilla floodplain (Val and Floramo, 2003) were considered to be suitable units. The combined floristic and tree health map was simplified to 35 unique FRM vegetation codes describing the major communities (Table 9). Tree health for each vegetation polygon was taken from the first tree health code of the vegetation mapping. These simplified vegetation community polygons were intersected with the FWIP divisions to create ~32,000 FRM vegetation polygons. Each FRM vegetation polygon within a FWIP division was identified as being either a wetland polygon, or a vegetation polygon on the highland or river side of the wetland. Intersecting the vegetation and FWIP division polygons meant that the FWIP salinisation risk from the model could be transferred to the appropriate vegetation polygon based on its location within the division relative to the wetland.
Table 9. Relationship between the simplified FRM vegetation codes and descriptions and the DEH 1:250,000 map sheet (MU_250) floristic groups.

<table>
<thead>
<tr>
<th>Regional Description</th>
<th>Regional Description</th>
<th>Regional Description</th>
<th>Structural Formation Description</th>
<th>General Formation Description</th>
<th>FRM Vegetation Code</th>
<th>FRM Vegetation Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus camaldulensis var. camaldulensis</td>
<td>E. largiflorens</td>
<td>Open Forest</td>
<td>Forest</td>
<td>RG_F</td>
<td>Red Gum Forest</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus camaldulensis var. camaldulensis</td>
<td>E. camaldulensis var. camaldulensis</td>
<td>Low Open Forest</td>
<td>Forest</td>
<td>BBRG_W</td>
<td>Black Box/Red Gum Woodland</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus largiflorens</td>
<td>Acacia stenophylla</td>
<td>Low Open Forest</td>
<td>Forest</td>
<td>BCCO_F</td>
<td>Black Box/Cooba Forest</td>
<td></td>
</tr>
<tr>
<td>Melaleuca lanceolata ssp. lacedata +/- Eucalyptus largiflorens</td>
<td>halmaturorum</td>
<td>Very Low Open Forest</td>
<td>Forest</td>
<td>TT_F</td>
<td>Tea Tree Forest</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus camaldulensis var. camaldulensis</td>
<td>Acacia stenophylla</td>
<td>Woodland</td>
<td>Woodland</td>
<td>RG_F</td>
<td>Red Gum Forest</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus camaldulensis var. camaldulensis</td>
<td>E. largiflorens</td>
<td>Woodland</td>
<td>Woodland</td>
<td>RGGW_W</td>
<td>Red Gum/Black Box Woodland</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus largiflorens</td>
<td>E. camaldulensis var. camaldulensis</td>
<td>Woodland</td>
<td>Woodland</td>
<td>BBRG_W</td>
<td>Black Box/Red Gum Woodland</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus largiflorens</td>
<td>Acacia stenophylla</td>
<td>Low Open Woodland</td>
<td>Woodland</td>
<td>BB_W</td>
<td>Black Box Woodland</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus porosa</td>
<td>Acacia stenophylla</td>
<td>Low Woodland</td>
<td>Woodland</td>
<td>CO_W</td>
<td>Cooba Woodland</td>
<td></td>
</tr>
<tr>
<td>Muehlenbeckia florulenta</td>
<td>Tall Shrubland</td>
<td>Shrubland</td>
<td>LIG_S</td>
<td>Lignum Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dodonaea viscosa ssp. angustissima</td>
<td>Open Shrubland</td>
<td>Shrubland</td>
<td>HOP_S</td>
<td>Hopbush Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atriplex rhagodioides</td>
<td>Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chenopodium nitrariaceum</td>
<td>Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salicornia quinqueflora</td>
<td>Low Closed Shrubland</td>
<td>Shrubland</td>
<td>HALO_S</td>
<td>Halophyte Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atriplex lindleyi ssp. lindleyi</td>
<td>Scleroaena muricata var. muricata</td>
<td>Low Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
</tr>
<tr>
<td>Halosarcia spp. and / or Scleroaena spp.</td>
<td>Scleroaena sedifolia</td>
<td>Low Open Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
</tr>
<tr>
<td>Sarcocornia quinqueflora</td>
<td>Low Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atriplex vesicaria +/- Maireana oppositifolia</td>
<td>Low Open Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maireana pyramidata</td>
<td>Low Open Shrubland</td>
<td>Shrubland</td>
<td>CHENO_S</td>
<td>Chenopod Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parachysonia triandra</td>
<td>Low Open Shrubland</td>
<td>Shrubland</td>
<td>HALO_S</td>
<td>Halophyte Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scleroaena tricuspis</td>
<td>scleroaena brachytera</td>
<td>Low Open Shrubland</td>
<td>Shrubland</td>
<td>HALO_S</td>
<td>Halophyte Shrubland</td>
<td></td>
</tr>
<tr>
<td>Phragmites australis +/- Typha domingensis +/- Schoenoplectus validus</td>
<td>Closed Tussock Grassland</td>
<td>Grassland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agrostis avenacea var. avenacea</td>
<td>Tussock Grassland</td>
<td>Grassland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sporobolus virginicus or Sporobolus bichili</td>
<td>Tussock Grassland</td>
<td>Grassland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stipa stipoides</td>
<td>Tussock Grassland</td>
<td>Grassland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eragrostis australis</td>
<td>Muehlenbeckia florulenta</td>
<td>Open Tussock Grassland</td>
<td>Grassland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
</tr>
<tr>
<td>Baumea juncea</td>
<td>Closed Sedgeland</td>
<td>Sedgeland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gahnia filum +/- Gahnia trifida</td>
<td>Juncus kraussii</td>
<td>Sedgeland</td>
<td>Sedgeland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
</tr>
<tr>
<td>Juncus kraussii</td>
<td>Sedgeland</td>
<td>Sedgeland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typha domingensis or Typha orientalis</td>
<td>Sedgeland</td>
<td>Sedgeland</td>
<td>WET</td>
<td>Wetland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angiantus tomentosus</td>
<td>Herbland</td>
<td>Herbland</td>
<td>HERB</td>
<td>Herbland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diphyllia crassifolium ssp. clavellatum</td>
<td>Very Open Mat Plants</td>
<td>Herbland</td>
<td>PIGF_H</td>
<td>Halophyte Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycalyx stuartii</td>
<td>Herbland</td>
<td>Herbland</td>
<td>HERB</td>
<td>Herbland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes: Where tree health was recorded but the trees were not the dominant species the FRM vegetation code was modified to include the tree species. For example CHENO_S becomes CHENO_RG where Red Gum is present in a Chenopod community.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.1.1 FWIP model salinisation risk

FWIP model salinisation risk was calculated using SIMPACT2 to provide the groundwater inflows to the floodplain arising from current irrigation and clearing and any irrigation expansion scenario (e.g. the ‘prior commitment’ claims scenario described in Section 4.5.1). These were then added to the estimated pre-irrigation/clearing inflows to provide the total groundwater inflows to the floodplain at the years 2000 (representing current conditions), 2020, 2050 and 2100, as described in Section 3.6. The groundwater inflows to the floodplain at each reporting time were used as inputs to the FWIP model, which predicted the floodplain salinisation risk for each division for each reporting time.

For a given FWIP scenario (e.g. current irrigation and clearing (2000)), the FWIP model salinisation risk was assigned to the vegetation polygons on the relevant parts of the floodplain if any evapotranspiration was predicted to occur. This simple cut off was chosen after inspection of the relationship between vegetation health and FWIP risk for the entire model area showed that ‘none’ and ‘some’ was the best predictor of vegetation health. Therefore, high FWIP salinisation risk was assigned to all vegetation polygons on the highland side of the wetland if any evapotranspiration was predicted to occur on the highland side of the wetland by the FWIP model. The wetland polygon was at risk of salinisation from groundwater discharge if there was upward movement of groundwater into the wetland. Similarly, a high FWIP risk was assigned to the vegetation polygons between the wetland and the river if there was any evapotranspiration predicted to occur on the river side of the wetland.

Using the ‘none’ and ‘some’ approach, about half of all vegetation polygons were given a high FWIP salinisation risk. However, only 41% of the vegetation mapping was indicative of floodplain salinisation, meaning that the FWIP salinisation risk was an over-estimate.

Therefore, the area of floodplain vegetation at risk of salinisation from groundwater discharge was calculated using the proportion of highland, wetland or river portions of the floodplain through which groundwater was predicted to be discharged as a probability rating. This approach mirrors that taken in the FWIP model (refer Section 3.6) and means that for a vegetation polygon in the highland portion of the floodplain where the FWIP model predicts that groundwater discharge occurs over 70% of the area, the vegetated area with high FWIP risk was calculated by multiplying the vegetation polygon area by a probability of 0.7.

4.1.2 FIM weir pool salinisation risk

The River Murray backwater data within the FIM was also used to spatially map the elevation of the river and anabranch creeks at entitlement flows. The difference between the floodplain surface elevation from the FIM and the nearest river and anabranch creek levels at entitlement was used to estimate the approximate groundwater depth below the floodplain surface due to weir pool levels alone. These values were used as an indicator of the salinity risk associated with weir pool levels. The difference between the area weighted floodplain surface and river level values calculated for each vegetation polygon were used to indicate the weir pool salinisation risk. As an example, if the area weighted floodplain surface elevation of a vegetation polygon was 13.8 m AHD and the river level at that point was 10.2 m AHD, then the calculated groundwater depth would be 3.6 m. Note that this does not account for raised groundwater levels associated with irrigation developments.

In areas where anabranch creeks bypass the weir, the river level of the vegetation polygons that were closer to the anabranch creek than the river was adjusted using creek heights that were interpolated between the points on the creek upstream and downstream of the weir. The interpolation was based on the best available information sourced from relevant groundwater models, measured heights and interpolation using a smoothed surface based on distance between the two points in the absence of better data.

Figure 34 and Table 10 show that for most soil types, 3.5 m depth is where the groundwater discharge rate asymptotes to a minimal value. Note that very sandy soils such as the Shonai
sand (Mehta et al. 1994) have shallow extinction depths, where groundwater discharge rates are less than 36.5 mm yr\(^{-1}\) when the groundwater is only 0.5 m deep. The groundwater discharge rate of the ‘Heavy alluvial clay’ measured by Wind (1955) is greater than 100 mm yr\(^{-1}\) when the groundwater is less than 2.0 m deep, but reduces to 44 mm yr\(^{-1}\) when the groundwater is 3.5 m deep. This soil type is likely to be similar to the areas of floodplain with heavy clay soils. A critical groundwater discharge rate to assess the risk of salinity hazard developing is \(\sim 0.1 \text{ mm d}^{-1}\) or 36.5 mm yr\(^{-1}\) for dryland areas and \(\sim 1 \text{ mm d}^{-1}\) or 365 mm yr\(^{-1}\) for irrigated areas (Peck, 1978). Therefore, the critical value for floodplain soils that are periodically inundated probably lies somewhere between these two values, i.e. in the range 36.5 to 365 mm yr\(^{-1}\). The criteria described by Peck (1978) indicate that a depth of 3.5 m in the Wind (1955) heavy alluvial clay, which has a groundwater discharge rate of 0.12 mm d\(^{-1}\) at 3.5 m depth, results in minimal salinisation risk.

Table 10. Groundwater discharge rates \((Q_{GW})\) for a range of soil types when the water table is at 2.0 and 3.5 m depth, where 36.5 mm yr\(^{-1}\) is a critical value for the assessment of salinity risk in dryland areas (adapted from Holland, 2002).

<table>
<thead>
<tr>
<th>Soil</th>
<th>(Q_{GW}) at 2.0 m depth (mm yr(^{-1}))</th>
<th>(Q_{GW}) at 3.5 m depth (mm yr(^{-1}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy alluvial clay</td>
<td>106.61</td>
<td>44.28</td>
<td>Wind, 1955</td>
</tr>
<tr>
<td>Pachappa fine sandy loam</td>
<td>258.13</td>
<td>48.17</td>
<td>Gardner and Fireman, 1958</td>
</tr>
<tr>
<td>Chino clay</td>
<td>247.67</td>
<td>80.87</td>
<td>Gardner and Fireman, 1958</td>
</tr>
<tr>
<td>Yolo light clay</td>
<td>90.06</td>
<td>29.41</td>
<td>Gardner and Fireman, 1958</td>
</tr>
<tr>
<td>Santa Ana sand</td>
<td>590.26</td>
<td>62.93</td>
<td>Willis, 1960</td>
</tr>
<tr>
<td>Diablo loam</td>
<td>157.61</td>
<td>51.46</td>
<td>Willis, 1960</td>
</tr>
<tr>
<td>Yandera loam</td>
<td>395.27</td>
<td>73.75</td>
<td>Talsma, 1963 Site 1</td>
</tr>
<tr>
<td>Banna sand</td>
<td>2,184</td>
<td>943.40</td>
<td>Talsma, 1963 Site 2</td>
</tr>
<tr>
<td>Camarooka clay loam</td>
<td>126.08</td>
<td>41.17</td>
<td>Talsma, 1963 Site 3</td>
</tr>
<tr>
<td>Jondaryan loam</td>
<td>90.06</td>
<td>29.41</td>
<td>Talsma, 1963 Site 5</td>
</tr>
<tr>
<td>S-W GAB alluvium</td>
<td>4.81</td>
<td>2.20</td>
<td>Thorburn et al., 1992</td>
</tr>
<tr>
<td>Aeolian sand</td>
<td>(2.14 \times 10^{-3})</td>
<td>4.90(\times 10^{-6})</td>
<td>Stolte et al., 1994</td>
</tr>
<tr>
<td>Fluvialite silt loam</td>
<td>0.17</td>
<td>3.19(\times 10^{-2})</td>
<td>Stolte et al., 1994</td>
</tr>
<tr>
<td>Aeolian silt loam</td>
<td>690.89</td>
<td>312.63</td>
<td>Stolte et al., 1994</td>
</tr>
<tr>
<td>Marine sandy loam</td>
<td>4.78</td>
<td>1.33</td>
<td>Stolte et al., 1994</td>
</tr>
<tr>
<td>Shonai sand</td>
<td>8.81(\times 10^{-5})</td>
<td>5.02(\times 10^{-7})</td>
<td>Mehta et al., 1994</td>
</tr>
</tbody>
</table>

\(^*\) Note: the soil name does not always accurately indicate its field texture

Figure 34. Relationship between groundwater depth and groundwater discharge rates for the range of soil types described in Table 10 (adapted from Holland, 2002).
Using the soil salinisation risk from groundwater depth criteria described above, the risk of salinisation associated with weir pool levels alone was separated into high, medium and low based on the area weighted floodplain groundwater depths. High weir pool salinisation risk was defined as those areas of the floodplain where the area weighted river level below the floodplain surface was \( \leq 2.0 \) m. A medium weir pool salinisation risk was assigned to those vegetation polygons where the area weighted river level below the floodplain surface was greater than 2.0 m, but \( \leq 3.5 \) m. Depths greater than 3.5 m were used to define low weir pool salinisation risk areas. The groundwater depths derived from the difference between the height of the river or creek and the floodplain surface represent a finer scale and more detailed assessment of soil salinisation risk. However, unlike the FWIP risk they do not take into account areas of the floodplain where the water table is above river level, such as areas adjacent to irrigation mounds. Therefore, while it is a more detailed assessment, it may be an underestimate of the floodplain salinisation risk, particularly on floodplains that are near irrigation areas.

4.1.3 FIM potential benefits from flooding and weir pool manipulation

The FIM was used to predict floodplain areas that were inundated as a result of a specified River Murray flow into South Australia, including the raising of any or all of the weir pools (to a maximum level of 0.5 m above normal operating levels). This was done by intersecting the 32,000 FRM vegetation and division polygons with the polygons from the FIM for each lock reach to create a very detailed map of vegetation, river flows and river heights that consisted of over a million polygons for the entire River Murray in South Australia. The area weighted flow to inundate and river height for each polygon was calculated by multiplying the polygon area by the river flow and river height and then calculating the average value for each of the 32,000 FRM vegetation polygons. Flows outside of the FIM were assigned a nominal flow of 150,000 ML d\(^{-1}\) and river height of 999.9 m.

In developing the FRM, it was necessary to determine the extent of the present-day ‘active’ floodplain in order to identify areas that could realistically be flooded under currently available water delivery options. As shown in Figure 8.2 of Sharley and Huggan (1995), ~95% of the Chowilla floodplain is inundated at a flow of 140,000 ML d\(^{-1}\). At this flow virtually all of the Red Gum and Black Box communities would be inundated. This flow has a return period under current conditions of 1 in 25 years, but under natural conditions occurred at a frequency of 1 in 7 years. Hence, 1 in 7 years appears to be the critical flow recurrence interval that defines the ‘active’ floodplain. Under current conditions this recurrence interval is equivalent to a flow of ~70,000 ML d\(^{-1}\). It is reasonable to assume that this applies to the rest of the floodplain and not just to the Chowilla floodplain. The area that comprises the ‘active’ floodplain coincidentally represents the maximum flow for which viable engineering options can be used to ‘water’ the floodplain. Therefore, a 70,000 ML d\(^{-1}\) flow or less represents a critical ecological and engineering threshold in the lower River Murray in South Australia.

So in the FRM, floodplain vegetation inundated at 70,000 ML d\(^{-1}\) or less was considered to be areas for potential flow management. In contrast, it is likely that areas that require a flow of greater than 70,000 ML d\(^{-1}\) to be inundated cannot be flooded as easily. The area weighted flow required to inundate each vegetation polygon that was calculated using the intersection of the FIM and the FRM vegetation polygons was used to determine whether a vegetation polygon could be inundated by a particular flow, e.g. 70,000 ML d\(^{-1}\). For the vegetated areas of the floodplain between the Border and Mannum, 39,242 ha or 42% are flooded at \( \leq 70,000 \) ML d\(^{-1}\) and 48,500 ha or 58% are flooded at > 70,000 ML d\(^{-1}\). Note that other flood threshold values can be used in the FRM. Each of the 32,000 FRM vegetation polygons had an area weighted value for river flow (ML d\(^{-1}\)) and river height (mAHHD). These values were used by the FRM to determine whether the vegetation polygon could be inundated by a 70,000 ML d\(^{-1}\) flood.
The potential benefits of weir pool manipulation are spatially variable, depending on the particular weir pool manipulation scenario that is being considered. Therefore, the FRM was designed so that individual vegetation polygons could be selected based on their spatial location with respect to the weir pool manipulation scenario being considered. Vegetation polygons were selected by spatial location using the ‘has their centre in’ option during the development of the FRM as this gave the best match between the weir pool manipulation scenario and the selected FRM vegetation polygons. Selected FRM vegetation polygons were assigned a value of one in the ‘WeirPoolRaising’ field, while a value of zero was used to indicate that the vegetation polygon was not inundated by the weir pool manipulation scenario.

4.2 Calculating the FRM salinisation and flooding risk classes

The FWIP salinisation risk, weir pool salinisation risk and flooding potential of each vegetation polygon were combined in the Floodplain Risk Methodology using the following seven classes as shown in Figure 35:

1. Areas of high FWIP salinisation risk, i.e. the FWIP model predicts that some groundwater discharge is occurring;
2. Areas of low FWIP salinisation risk, i.e. the FWIP model predicts that no groundwater discharge is occurring;
3. Areas of high weir pool salinisation risk, i.e. the river level at entitlement is less than or equal to 2.0 m below the floodplain surface and therefore it is highly likely that localised groundwater discharge is occurring due to the weir pool alone;
4. Areas of medium weir pool salinisation risk, i.e. the river level at entitlement is greater than 2.0 m and less than or equal to 3.5 m below the floodplain surface and therefore it is likely that localised groundwater discharge is occurring due to the weir pool alone;
5. Areas of low weir pool salinisation risk, i.e. the river level at entitlement is greater than 3.5 m below the floodplain surface and therefore it is not likely that localised groundwater discharge is occurring due to the weir pool alone;
6. Areas where there is flooding, i.e. when the ‘70,000 ML d⁻¹’ scenario is selected, the area weighted flow is less than or equal to 70,000 ML d⁻¹; and when the ‘weir pool raising’ scenario is selected, the area falls within the flooded area described by the weir pool raising scenario; and
7. Areas where there is no flooding, i.e. when the ‘70,000 ML d⁻¹’ scenario is selected, the area weighted flow is greater than 70,000 ML d⁻¹ and when the ‘weir pool raising’ scenario is selected, the area falls outside of the flooded area described by the weir pool raising scenario.
Figure 35. Schematic describing the development of the 60 FRM classes based on the five tree health, two FWIP salinisation risk, three weir pool salinisation risk and two flooding classes.

Figure 36 gives an example of the four data sets that were combined to produce the FRM Salinisation Risk and Flooding Classes for the floodplain area between Lock 3 and Lock 4 in the Riverland in South Australia. The top left panel in Figure 36 shows the distribution of tree health classes in the area of interest, where healthy, unhealthy and dead trees are shown in green, orange and red, respectively. Areas dominated by halophytic vegetation, such as Halosarcia, Sarcocornia, Pachycornia or Suaeda spp. that are indicators of salinity are shown in pink to separate them from other non tree vegetation on the floodplain. These vegetation classes can be used to identify areas where salinity and / or drought have affected the vegetation community.

The top right panel in Figure 36 shows the FWIP salinisation risk for each vegetation polygon. The FWIP salinisation risk was based on the whether any groundwater discharge was predicted in that vegetation polygon. This probability was derived from the proportion of that part of the division (highland, wetland or river parts of each division) where the water table was within the model vegetation rooting depth and therefore through which groundwater discharge was predicted.
Figure 36. Input data used to determine FRM salinisation and flooding risk classes, (clockwise from top left) simplified tree health classification of the vegetation polygons; FWIP salinisation risk showing floodplain vegetation, seepage and wetland areas at risk of salinisation from groundwater discharge; weir pool salinisation risk areas where the river level is ≤ 2.0 m, 2.0 to 3.5 m and >3.5 m below the floodplain surface; and areas inundated by a 70,000 ML d⁻¹ flood.
The bottom right panel in Figure 36 shows the locations of the three classes of weir pool salinisation risk, where the floodplain surface was less than or equal to 2.0 m above river level (high weir pool salinisation risk), between 2.0 m and 3.5 m above river level (medium weir pool salinisation risk) and greater than 3.5 m above river level (low weir pool salinisation risk). This is a fine scale dataset that shows the risk of salinisation associated with weir pool level alone and does not include the effect of irrigation developments on the floodplain water table depth.

The bottom left panel in Figure 36 shows the areas inundated by a 70,000 ML d⁻¹ flood. These areas are within what was classed as the ‘active’ floodplain and are also the extent of floodplain areas that can be watered by viable engineering options. The alternative criterion to assess the potential benefits of periodic flooding as described above is the area inundated by a specific weir pool manipulation scenario. The flooding criterion can be changed to other flow values and areas inundated by artificial floods.

These seven salinisation risk and potential flooding benefits categories were combined using the flow chart in Figure 35 to create twelve possible FRM salinisation risk and flooding classes. The six FWIP and weir pool salinisation risk classes are shown for the area between Lock 3 and Lock 4 in Figure 37. This example shows that the areas of high FWIP and high weir pool salinisation risk (red areas) are located immediately upstream of Locks 3 and 4. There are also high FWIP and weir pool salinisation risk classes associated with several of the floodplains adjacent the Loxton Irrigation Area (red and orange areas). The Bookpurnong floodplain, downstream of Lock 4 has a combination of high FWIP and medium to low weir pool salinisation classes, depending on floodplain elevation.

![Figure 37](image-url)
The six FWIP and weir pool salinisation risk classes can be interpreted as follows:

- **High FWIP and high weir pool salinisation risk**
  These areas are predicted to receive groundwater discharge by the FWIP model and the river level is close to the floodplain surface. It is likely that these areas are immediately upstream of the nearest weir. The FWIP salinisation risk may be related to the raised weir pool levels and/or groundwater inflows. It is likely that floodplain groundwater levels in these areas would be difficult to manage because they are close to river level, meaning that floodplain bores may not be able to achieve significant draw-down of groundwater levels. However, being low in the landscape and upstream of a weir, it is likely that some of these areas are vegetated by healthy trees that are underlain by relatively fresh groundwater and receive frequent flooding. This class is also likely to include many of the halophytes commonly seen upstream of weirs growing over saline groundwater.

- **High FWIP and medium weir pool salinisation risk**
  These areas are predicted to receive groundwater discharge by the FWIP model, and the river level is moderately deep. It is likely that these areas are midway between two weirs. The FWIP salinisation risk is likely to be related to the combination of relatively high groundwater inflows and high river levels due to the weirs. This class may benefit from salt interception to reduce the amount of groundwater inflows, thus reducing the rate of groundwater discharge and salinisation risk. The medium weir pool risk suggests that they may be within the more frequent small to medium sized floods, making flow management possible.

- **High FWIP and low weir pool salinisation risk**
  These areas are predicted to receive groundwater discharge by the FWIP model, but the river level is relatively deep. It is likely that these areas are downstream of the nearest weir and the FWIP salinisation risk is likely to be related to high groundwater inflows, which is likely to be associated with irrigation development. This suggests that these floodplain areas may benefit from salt interception to reduce the amount of groundwater inflows, thus reducing the rate of groundwater discharge and salinisation risk. The low weir pool risk suggests that they may be relatively high on the floodplain and therefore outside of the more frequent small to medium sized floods, making flow management more difficult.

- **Low FWIP and high weir pool salinisation risk**
  These areas are predicted to receive no groundwater discharge by the FWIP model, but the river level is close to the floodplain surface. It is likely that these areas are in the middle of the weir pool, but are in low lying parts of the floodplain that are distant from highland irrigation development, or located on narrow floodplains. This suggests that in areas underlain by saline groundwater there is likely to be salt accumulation in the soil profile. This class may also include low lying areas of the floodplain underlain by relatively fresh groundwater, typical of the inside of river bends that are vegetated by healthy trees and are regularly flooded. Increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may threaten these areas.

- **Low FWIP and medium weir pool salinisation risk**
  These areas are predicted to receive no groundwater discharge by the FWIP model, and have a moderately deep river level, meaning they are likely to be relatively high on the floodplain. It is likely that these areas are midway between two weirs and distant from highland irrigation development, or located on narrow floodplains. The medium weir pool risk suggests that they may be within the more frequent small to medium sized floods and/or weir pool manipulation areas, making flow management more difficult.
possible. Increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may threaten these areas.

- **Low FWIP and low weir pool salinisation risk**
  
  These areas are predicted to receive no groundwater discharge by the FWIP model, and have a relatively deep river level, meaning they are likely to be high on the floodplain. It is likely that these areas are downstream of the nearest weir and distant from highland irrigation development, or located on narrow floodplains. It is likely that some of these trees are unhealthy despite the low FWIP and low weir pool salinisation risk because they are relatively high on the floodplain. This means that they are outside of the more frequent small to medium sized floods and their health may have declined due to a reduction in flooding frequency and duration under the current flow regime. Increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may threaten these areas.

These six salinisation risk classes were grouped into three management options:

1. **Salt Interception Scheme (SIS) to control groundwater inflows**

   These areas are currently at high FWIP salinisation risk, but have medium to low weir pool salinisation risk, which suggests that they may benefit from salt interception to reduce the amount of groundwater inflows, thus reducing the rate of groundwater discharge and salinisation risk. Some of these areas may be within the more frequent small to medium sized floods, making flow management possible.

2. **Protect from future salinisation risks**

   These areas are currently at low FWIP salinisation risk and have medium to low weir pool salinisation risk, which means that increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may threaten these areas. Some of these areas may be within the more frequent small to medium sized floods, making flow management possible.

3. **Limited management options available**

   These areas have a high weir pool salinisation risk. Therefore, it is likely that floodplain groundwater levels in these areas would be difficult to manage because they are close to river level. However, being low in the landscape, it is likely that if the groundwater is relatively fresh then they are vegetated by healthy trees, whereas if the groundwater is more saline, then they may be vegetated by halophytes.

Having determined the salinisation risk, the potential to flood each vegetation polygon for a given flow or weir pool manipulation scenario was determined using the area weighted flow, or in the case of the weir pool raising scenario, whether the polygon was flooded. This meant that the six salinisation risk classes were split into twelve salinisation risk and flooding potential classes. When combined with the five tree health codes (Healthy trees, Unhealthy trees, Dead trees, Not tree and Halophytes), this created 60 tree health – FWIP salinisation risk – weir pool salinisation risk – and flooding potential codes. The tree health codes were added to the salinisation risk and flooding potential classes to assist in the analysis of the data during model validation.

The 60 FRM codes were programmed within the ESRI ArcGIS 8 GIS program using the Visual Basic language. Appendix C lists the major Visual Basic code that constitutes the FRM. The FRM contains ~32,000 vegetation polygons with a unique FRMID. The FRM layer was used to store the FWIP salinisation risk from the relevant FWIP model table, the area weighted groundwater depth, river flow for inundation and position within the floodplain division relative to the highland, wetland and river. Table C1 in Appendix C summarises the fields in the FRM dataset.
4.3 Current irrigation and clearing (2000) and a 70,000 ML d$^{-1}$ flood

The FWIP model showed that the groundwater inflows from current irrigation and clearing (2000) predicted that 35.9% of the floodplain was at risk of floodplain salinisation. Table 11 shows the vegetated area (ha) and proportion of each salinisation risk and flooding class (%) vegetated by healthy trees, unhealthy trees, dead trees, halophytes and not tree vegetation. A greater proportion of healthy and unhealthy trees were in the low FWIP salinisation risk class (25% healthy and 30% unhealthy) than the high FWIP salinisation risk class (13% healthy and 17% unhealthy). The proportion of dead trees was comparable between the two FWIP salinisation risk classes. There was a greater proportion of halophytes and not tree vegetation in the high FWIP salinisation risk class (17% halophytes and 49% not tree) than in the low FWIP salinisation risk class (11% halophytes and 32% not tree). This indicates that the high and low FWIP salinisation risk classes were related to the distribution of vegetation indicators of high and low salinity.

Table 11 shows that the high weir pool salinisation risk class had the greatest proportions of not tree vegetation (50%) and halophytes (15%). This is typical of low lying parts of the floodplain that are vegetated by lignum, wetland and samphire species. The greatest proportion of healthy trees was found in the medium weir pool salinisation risk class (23% healthy trees), although healthy trees were evenly distributed between the three weir pool salinisation risk classes, comprising ~20% of each class. The low weir pool salinisation risk class contained the greatest proportion of unhealthy trees (37%). It is likely that despite the low weir pool salinisation risk in these areas, their relatively high elevation means that they are infrequently flooded.

Table 11. Current irrigation and clearing (2000) – 70,000 ML d$^{-1}$ flood. Summary of the vegetated area (ha) and proportion of each salinisation risk and flooding class (%) vegetated by healthy trees, unhealthy trees, dead trees, halophytes and non tree species.

<table>
<thead>
<tr>
<th>Current irrigation and clearing (2000) – 70,000 ML d$^{-1}$ flood</th>
<th>FWIP Salinisation Risk</th>
<th>Weir Pool Salinisation Risk</th>
<th>Flooding (ML d$^{-1}$)</th>
<th>Total area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Healthy</td>
<td>Unhealthy</td>
<td>Dead</td>
<td>Halophytes</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>4,135</td>
<td>13,834</td>
<td>5,620</td>
<td>6,386</td>
</tr>
<tr>
<td>% class area</td>
<td>13%</td>
<td>25%</td>
<td>18%</td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td>5,349</td>
<td>16,689</td>
<td>3,959</td>
<td>7,357</td>
</tr>
<tr>
<td>% class area</td>
<td>17%</td>
<td>30%</td>
<td>13%</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>1,025</td>
<td>1,536</td>
<td>1,217</td>
<td>886</td>
</tr>
<tr>
<td>% class area</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>5,433</td>
<td>6,297</td>
<td>4,595</td>
<td>3,623</td>
</tr>
<tr>
<td>% class area</td>
<td>17%</td>
<td>11%</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>15,585</td>
<td>17,860</td>
<td>15,584</td>
<td>9,592</td>
</tr>
<tr>
<td>% class area</td>
<td>49%</td>
<td>32%</td>
<td>50%</td>
<td>34%</td>
</tr>
<tr>
<td>Total (ha)</td>
<td>31,527</td>
<td>56,215</td>
<td>30,975</td>
<td>27,843</td>
</tr>
<tr>
<td>% total area</td>
<td>36%</td>
<td>64%</td>
<td>35%</td>
<td>32%</td>
</tr>
</tbody>
</table>

Healthy trees were also evenly distributed between the two flooding classes in Table 11, whereas the ≤70,000 ML d$^{-1}$ flooding class contained greater proportions of not tree vegetation (50%) and dead trees (4%) than the >70,000 ML d$^{-1}$ flooding class. The areas of dead trees may be related to areas that were drowned following the construction of the locks and weirs in the 1920s and 1930s. The not tree vegetation in this ≤70,000 ML d$^{-1}$ flooding class was a mixture of lignum and chenopods. The >70,000 ML d$^{-1}$ flooding class contained the greatest proportions of unhealthy trees (33%) and halophytes (16%), although most of the area was covered by non tree vegetation (28%), which inspection of the vegetation codes showed was predominantly chenopods. This is likely to be related to the relatively low
flooding frequency of these areas and the resultant dryness and salinisation of the soil profiles in the areas outside of the ‘active’ floodplain.

Figure 38 shows an example of the areas of healthy and unhealthy trees (45% of the vegetated floodplain) that are in each of the six salinisation risk classes and whether they can be inundated by a 70,000 ML d⁻¹ flood from between Lock 3 and Lock 4. Note that the medium and high weir pool salinisation risk classes have been merged in this figure. It shows the location of the high FWIP salinisation risk areas adjacent the Berri–Barmera, Bookpurnong and Loxton LWMP areas and upstream of Lock 3 and Lock 4. The separation of the medium to high weir pool salinisation risk from the low weir pool salinisation risk separates the Bookpurnong floodplain downstream of Lock 4 into the healthy trees along the river and the mixed health of the trees nearer the highland.

Table 12 and Figure 39 show the vegetated area (ha) in each of the 60 tree health, FWIP salinisation risk, weir pool salinisation risk and flooding classes. Over three quarters of the healthy (77%) and unhealthy (76%) trees were in the low FWIP salinisation risk class. Most of these trees were in the medium to low weir pool salinisation risk and >70,000 ML d⁻¹ flooding classes (39% of the healthy and 54% of the unhealthy trees). This suggests that these healthy and unhealthy trees are relatively high on the floodplain and that the unhealthy trees may be unhealthy due to lack of flooding. The low FWIP, medium to high weir pool salinisation risk and ≤70,000 ML d⁻¹ flooding classes contained a greater proportion of healthy (30%) than unhealthy (18%) trees. This may be related to the more frequent flooding of these areas and it may also indicate that the groundwater in these areas is relatively fresh. The low FWIP, medium to high weir pool salinisation risk and ≤70,000 ML d⁻¹ flooding classes also contained the greatest proportion of dead trees (41%), which may have been drowned by the construction of the weirs or be related to shallow saline water tables typical of low lying parts of the floodplain upstream of the nearest weir.

The halophytes were predominantly in the low lying parts of the landscape (72% of all halophyte vegetation were in the high and medium weir pool salinisation risk classes). However, the low FWIP and low weir pool salinisation risk and >70,000 ML d⁻¹ flooding class also contained 16% of all halophyte vegetation, which suggests that some of the halophytes were higher up on the floodplain.

The not tree vegetation was evenly distributed between the high and low FWIP salinisation risk classes (47% high FWIP and 53% low FWIP). However, the not tree vegetation comprised almost half (49%) of the high FWIP salinisation risk class area, compared to a third (32%) of the low FWIP salinisation risk class area. The not tree vegetation was mostly in the high FWIP and high weir pool salinisation risk and >70,000 ML d⁻¹ flooding class areas (31% of all not tree vegetation). Inspection of the vegetation codes for this class reveals that chenopods (72%) comprise most of the not tree vegetation in this class, which is typical of elevated areas that are infrequently flooded. The vegetation codes for the low FWIP salinisation risk show that lignum (52%) was dominant. This suggests that the FWIP and weir pool salinisation risk classes were able to distinguish between the two most common types of not tree vegetation.
Figure 38. Current irrigation and clearing (2000) – 70,000 ML d$^{-1}$ flood. Example of the tree health, flooding and salinisation risk classes between Locks 3 and 4. Areas of healthy trees, outside of the 70,000 ML d$^{-1}$ flood are shown in light green; areas of healthy trees, within the 70,000 ML d$^{-1}$ flood are shown in dark green; areas of unhealthy trees, outside of the 70,000 ML d$^{-1}$ flood are shown in orange; and areas of unhealthy trees, within the 70,000 ML d$^{-1}$ flood are shown in dark orange.
### Table 12. Current Irrigation and Clearing (2000) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in each of the 60 tree health, FWIP salinisation risk, weir pool salinisation risk and flooding classes. The high FWIP salinisation risk results are in the upper portion of the table, while the low salinisation risk classes are in the lower portion of the table.

<table>
<thead>
<tr>
<th>FWIP salinisation risk</th>
<th>Weir pool salinisation risk</th>
<th>Flooding (ML d⁻¹)</th>
<th>Healthy tree area (ha)</th>
<th>% Healthy tree area</th>
<th>Unhealthy tree area (ha)</th>
<th>% Unhealthy tree area</th>
<th>Dead tree area (ha)</th>
<th>% Dead tree area</th>
<th>Halophyte area (ha)</th>
<th>% Halophyte area</th>
<th>Not Tree area (ha)</th>
<th>% Not Tree area</th>
<th>Total area (ha)</th>
<th>% total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>≤ 70,000</td>
<td>1,288</td>
<td>7%</td>
<td>537</td>
<td>2%</td>
<td>227</td>
<td>9%</td>
<td>1,257</td>
<td>11%</td>
<td>1,057</td>
<td>3%</td>
<td>4,367</td>
<td>5%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>691</td>
<td>4%</td>
<td>1,106</td>
<td>5%</td>
<td>342</td>
<td>13%</td>
<td>1,353</td>
<td>12%</td>
<td>10,418</td>
<td>31%</td>
<td>13,910</td>
<td>16%</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>≤ 70,000</td>
<td>213</td>
<td>1%</td>
<td>2,052</td>
<td>9%</td>
<td>160</td>
<td>6%</td>
<td>1,483</td>
<td>13%</td>
<td>2,311</td>
<td>7%</td>
<td>6,219</td>
<td>7%</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>&gt; 70,000</td>
<td>646</td>
<td>4%</td>
<td>213</td>
<td>1%</td>
<td>13</td>
<td>1%</td>
<td>34</td>
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<td>178</td>
<td>1%</td>
<td>1,084</td>
<td>1%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>≤ 70,000</td>
<td>114</td>
<td>1%</td>
<td>1,046</td>
<td>5%</td>
<td>193</td>
<td>8%</td>
<td>34</td>
<td>10%</td>
<td>90</td>
<td>3%</td>
<td>3,422</td>
<td>4%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>1,182</td>
<td>7%</td>
<td>395</td>
<td>2%</td>
<td>90</td>
<td>2%</td>
<td>1,161</td>
<td>1%</td>
<td>712</td>
<td>2%</td>
<td>2,525</td>
<td>3%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>4,135</td>
<td>23%</td>
<td>5,349</td>
<td>24%</td>
<td>1,025</td>
<td>40%</td>
<td>5,433</td>
<td>46%</td>
<td>15,585</td>
<td>47%</td>
<td>31,527</td>
<td>36%</td>
</tr>
</tbody>
</table>

### Current Irrigation and Clearing (2000) – 70,000 ML d⁻¹ flood

<table>
<thead>
<tr>
<th>FWIP salinisation risk</th>
<th>Weir pool salinisation risk</th>
<th>Flooding (ML d⁻¹)</th>
<th>Healthy tree area (ha)</th>
<th>% Healthy tree area</th>
<th>Unhealthy tree area (ha)</th>
<th>% Unhealthy tree area</th>
<th>Dead tree area (ha)</th>
<th>% Dead tree area</th>
<th>Halophyte area (ha)</th>
<th>% Halophyte area</th>
<th>Not Tree area (ha)</th>
<th>% Not Tree area</th>
<th>Total area (ha)</th>
<th>% total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>High</td>
<td>≤ 70,000</td>
<td>2,964</td>
<td>16%</td>
<td>1,975</td>
<td>9%</td>
<td>609</td>
<td>24%</td>
<td>1,640</td>
<td>14%</td>
<td>3,416</td>
<td>10%</td>
<td>10,604</td>
<td>12%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>676</td>
<td>4%</td>
<td>341</td>
<td>2%</td>
<td>39</td>
<td>2%</td>
<td>345</td>
<td>3%</td>
<td>693</td>
<td>2%</td>
<td>2,094</td>
<td>2%</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>≤ 70,000</td>
<td>2,429</td>
<td>14%</td>
<td>1,974</td>
<td>9%</td>
<td>443</td>
<td>17%</td>
<td>826</td>
<td>7%</td>
<td>3,983</td>
<td>12%</td>
<td>9,654</td>
<td>11%</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>&gt; 70,000</td>
<td>3,098</td>
<td>17%</td>
<td>3,942</td>
<td>18%</td>
<td>161</td>
<td>6%</td>
<td>1,490</td>
<td>13%</td>
<td>3,989</td>
<td>12%</td>
<td>12,679</td>
<td>14%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>≤ 70,000</td>
<td>655</td>
<td>4%</td>
<td>469</td>
<td>2%</td>
<td>33</td>
<td>1%</td>
<td>113</td>
<td>1%</td>
<td>1,099</td>
<td>3%</td>
<td>2,369</td>
<td>3%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>4,012</td>
<td>22%</td>
<td>7,988</td>
<td>36%</td>
<td>251</td>
<td>10%</td>
<td>1,883</td>
<td>16%</td>
<td>4,680</td>
<td>14%</td>
<td>18,815</td>
<td>21%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>&gt; 70,000</td>
<td>13,834</td>
<td>77%</td>
<td>16,689</td>
<td>76%</td>
<td>1,536</td>
<td>60%</td>
<td>6,297</td>
<td>54%</td>
<td>17,860</td>
<td>53%</td>
<td>56,215</td>
<td>64%</td>
</tr>
</tbody>
</table>
The Floodplain Risk Methodology (FRM)

Figure 39. Current irrigation and clearing (2000) – 70,000 ML d⁻¹ flood. Areas with high FWIP and high weir pool salinisation risk are shown in red, high FWIP and medium weir pool salinisation risk are shown in orange, high FWIP and low weir pool salinisation risk are shown in light red, low FWIP and high weir pool salinisation risk are shown in dark brown, low FWIP and medium weir pool salinisation risk are shown in light brown and low FWIP and low weir pool salinisation risk are shown in beige. Areas within a 70,000 ML d⁻¹ flood are shown in solid, while areas outside a 70,000 ML d⁻¹ flood are hatched.

The data in Table 12 were plotted in Figure 40 to show the relationship between flooding and weir pool salinisation risk, where both are related to floodplain elevation and river levels. It shows that most of the floodplain vegetation in the high weir pool salinisation risk class is within a 70,000 ML d⁻¹ flood, whereas most of the vegetation in the low weir pool salinisation risk class is outside of a 70,000 ML d⁻¹ flood.

Figure 40. Current Irrigation and Clearing (2000) – 70,000 ML d⁻¹ flood. Comparison between the two flooding classes for each of the six FWIP and weir pool salinisation risk classes. It shows the relationship between flooding and weir pool salinisation risk, where both are related to floodplain elevation and river levels.
In summary, over three quarters of the healthy and unhealthy trees were located in the low FWIP salinisation risk class, in comparison to only 64% of the entire vegetated area. Most of these trees were in the medium to low weir pool salinisation risk, but were outside of the 70,000 ML d⁻¹ flood. There were a greater proportion of healthy than unhealthy trees in the low FWIP, medium to high weir pool salinisation risk and ≤70,000 ML d⁻¹ flood class, which may be related to the more frequent flooding of these areas and it may also indicate that the groundwater in these areas is relatively fresh. Most of the halophytes were in the low lying parts of the landscape, medium to high weir pool salinisation risk (72%). The FWIP and weir pool salinisation risk classes were able to distinguish between the two dominant not tree vegetation types. Chenopods (72%) dominated the not tree vegetation in the high FWIP, high weir pool salinisation risk and >70,000 ML d⁻¹ flooding class, whereas lignum was dominant in the low FWIP salinisation risk areas. A strong relationship between flooding and weir pool salinisation risk, which are both related to floodplain elevation and river levels was observed.

4.4 Current irrigation and clearing (2100) and a 70,000 ML d⁻¹ flood

The groundwater inflows to the river valley were predicted to double between 2000 and 2100. The FWIP model current irrigation and clearing (2100) scenario predicted that an additional 2,889 ha or 3% of floodplain vegetation would be at high FWIP salinisation risk in 2100 (Table 13). The seepage risk was predicted to increase by 70 km (166.7%) and salt loads to the river and wetlands by 977 tonnes d⁻¹ (82.4%) between 2000 and 2100. The location of the FWIP salinisation risk areas upstream of the nearest weir and adjacent to existing irrigation areas suggest that these floodplains have limited capacity to discharge more water by evapotranspiration as the groundwater is already within the vegetation rooting depth in many of these areas. Therefore, the majority of additional groundwater inflows that occur between 2000 and 2100 were predicted to be discharged as seepage and as groundwater inflows to the river and wetlands.

Figure 41 shows an example of the areas of healthy and unhealthy trees (45% of the vegetated floodplain) that are in each of the six salinisation risk classes and whether they can be inundated by a 70,000 ML d⁻¹ flood from between Lock 3 and Lock 4. Note that the medium and high weir pool salinisation risk classes have been merged in this figure. The FRM predictions for current irrigation and clearing (2100) and a 70,000 ML d⁻¹ flood indicate that the greatest increase in the high FWIP salinisation risk class occurred in the medium weir pool salinisation risk class (from 5,509 to 6,888 ha). Over 1,300 ha of floodplain vegetation that was at low FWIP, medium weir pool salinisation risk in 2000 were predicted to be at high FWIP, medium weir pool salinisation risk in 2100. Almost 1,000 ha of this vegetation was outside of a 70,000 ML d⁻¹ flood, indicating that it would be difficult to ameliorate the increased FWIP salinisation risk with flooding. Table 12 showed that most of the healthy (5,527 ha or 31% of the healthy trees) and unhealthy (5,916 ha or 27% of the unhealthy trees) trees were in the low FWIP, medium weir pool salinisation risk class. This means that 1,379 ha of vegetation that was at low FWIP salinisation risk in 2000 were predicted to be at high FWIP salinisation risk in 2100. Table 12 also showed that healthy and unhealthy trees comprise half of the low FWIP, medium weir pool salinisation risk class, suggesting that an additional 700 ha of healthy and unhealthy trees were at greater risk of salinisation due to groundwater discharge associated with current irrigation and clearing in 2100 than in 2000.
Figure 41. Current irrigation and clearing (2100) – 70,000 ML d⁻¹ flood. Example of the tree health, flooding and salinisation risk classes between Locks 3 and 4 for 2100. Areas of healthy trees, outside of the 70,000 ML d⁻¹ flood are shown in light green; areas of healthy trees, within the 70,000 ML d⁻¹ flood are shown in dark green; areas of unhealthy trees, outside of the 70,000 ML d⁻¹ flood are shown in orange; and areas of unhealthy trees, within the 70,000 ML d⁻¹ flood are shown in dark orange.
Table 13. Current irrigation and clearing (2100) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes.

<table>
<thead>
<tr>
<th>Salinisation risk</th>
<th>Floodings (ML d⁻¹)</th>
<th>Current (2000) vegetated area (ha)</th>
<th>Predicted (2100) vegetated area (ha)</th>
<th>Change in vegetated area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWI P Weir pool</td>
<td>≤70,000</td>
<td>14,507 17%</td>
<td>15,244 17%</td>
<td>737 +5%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>3,770 4%</td>
<td>3,888 4%</td>
<td>118 +3%</td>
</tr>
<tr>
<td></td>
<td>≤70,000</td>
<td>1,555 2%</td>
<td>1,980 2%</td>
<td>425 +27%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>3,954 5%</td>
<td>4,908 6%</td>
<td>954 +24%</td>
</tr>
<tr>
<td></td>
<td>≤70,000</td>
<td>552 1%</td>
<td>561 1%</td>
<td>9 +2%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>7,188 8%</td>
<td>7,834 9%</td>
<td>646 +9%</td>
</tr>
<tr>
<td></td>
<td>≤70,000</td>
<td>10,604 12%</td>
<td>9,868 11%</td>
<td>-736 -7%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>2,094 2%</td>
<td>1,976 2%</td>
<td>-118 -6%</td>
</tr>
<tr>
<td></td>
<td>≤70,000</td>
<td>9,654 11%</td>
<td>9,229 11%</td>
<td>-425 -4%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>12,679 14%</td>
<td>11,726 13%</td>
<td>-953 -8%</td>
</tr>
<tr>
<td></td>
<td>≤70,000</td>
<td>2,369 3%</td>
<td>2,359 3%</td>
<td>-10 0%</td>
</tr>
<tr>
<td></td>
<td>&gt;70,000</td>
<td>18,815 21%</td>
<td>18,169 21%</td>
<td>-646 -3%</td>
</tr>
<tr>
<td>Total</td>
<td>87,742</td>
<td>87,742</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.5 Example Scenario Predictions

This section details the application of the FWIP model and FRM to three example scenarios:

1) Irrigation Expansion from Prior Commitments;
2) Weir Pool Raising of 0.5 m; and
3) Proposed Salt Interception Schemes.

These scenarios demonstrate the way in which the methodology could be applied to examine the impacts and benefits of potential management options. While the scenarios are considered to be realistic they are not current government policy. The analysis of each scenario demonstrates the manner in which the FWIP model and Floodplain Risk Methodology can be applied as a decision support tool in the formulation of floodplain management policies.

4.5.1 Irrigation Expansion from Prior Commitments

As part of the salinity policy formulation process in DWLBC, all irrigators with potential claims on ‘prior commitment’ status were identified. This process recorded the potential size (volume of allocation) and location of irrigation that may cause salinity debits to accrue without the corresponding need to generate its own offset salinity credits. Originally this was assessed using SIMPACT2 to estimate the potential draw down of credits that may occur. In choosing a future development scenario for this project, it was decided to use this existing prior commitment information.

All of the 6,780 ha of prior commitment developments were assessed in SIMPACT2. It was assumed that the new developments were applied at 10 ML ha⁻¹ (as in the salinity assessments) and began in 2010. Since all prior commitment developments were assumed to start in the same year, only one output grid layer of flux increases per target date was needed to distribute the fluxes laterally, as per Section 3.5. The predicted groundwater inflows to the river valley at 2050 and 2100 were then added to those for current irrigation with ‘legacy of history’ to make the FWIP predictions.
Figures 42 and 43 show the location of the ‘prior commitment’ irrigation claims and the resultant inflows to the river valley, and the FWIP floodplain salinisation and seepage risk at 2050 and 2100. No results are presented for the Lock 1 to Mannum reach as there were no ‘prior commitment’ claims in this area. Note that the ‘prior commitment’ areas have been represented as circles in these figures to protect the privacy of the claimants. These figures show that the prior commitment claims are concentrated in the Murtho LWMP Area. Table 14 provides a summary of FWIP predictions for the years 2050 and 2100 for current irrigation with ‘legacy of history’, and for current irrigation with ‘legacy of history’ plus the ‘prior commitment’ irrigation claims.

Table 14. Prior commitment claims (2050 and 2100). Summary of FWIP predictions for the years 2000 and 2100 for current irrigation with ‘legacy of history’ and for current irrigation with ‘legacy of history’ plus the ‘prior commitment’ irrigation claims for 2050 and 2100.

<table>
<thead>
<tr>
<th></th>
<th>Current Irrigation 2000</th>
<th>Current + Prior Commitments 2050</th>
<th>Current + Prior Commitments 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater inflows to the river valley (m³ d⁻¹)</td>
<td>75,444</td>
<td>152,274</td>
<td>111,218</td>
</tr>
<tr>
<td>Salt load to river (tonnes d⁻¹)</td>
<td>869</td>
<td>1,678</td>
<td>1,267</td>
</tr>
<tr>
<td>Salt load to wetlands (tonnes d⁻¹)</td>
<td>317</td>
<td>486</td>
<td>405</td>
</tr>
<tr>
<td>Salt load to river and wetlands (tonnes d⁻¹)</td>
<td>1,186</td>
<td>2,163</td>
<td>1,672</td>
</tr>
<tr>
<td>Length of modelled floodplain edge with seepage (km)</td>
<td>42</td>
<td>112</td>
<td>91</td>
</tr>
<tr>
<td>Total length of edge of modelled floodplain (km)</td>
<td>957</td>
<td>957</td>
<td>957</td>
</tr>
<tr>
<td>Modelled floodplain edge with seepage</td>
<td>4.4%</td>
<td>11.7%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on highland side of wetland (ha)</td>
<td>9,456</td>
<td>10,454</td>
<td>10,050</td>
</tr>
<tr>
<td>Wetland area at salinity risk (ha)</td>
<td>9,644</td>
<td>9,702</td>
<td>9,690</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on river side of wetland (ha)</td>
<td>12,427</td>
<td>14,259</td>
<td>13,352</td>
</tr>
<tr>
<td><strong>Total vegetation area on floodplain (ha)</strong></td>
<td><strong>87,742</strong></td>
<td><strong>87,742</strong></td>
<td><strong>87,742</strong></td>
</tr>
<tr>
<td>Vegetation and wetlands at salinity risk</td>
<td>35.9%</td>
<td>39.2%</td>
<td>37.7%</td>
</tr>
</tbody>
</table>

Comparison of Tables 6 and 14 and Figures 30 (Current irrigation and clearing – 2000) and 42 (Prior commitment claims – 2050) showed that in 2050 there was an additional 5 km (from 86 km to 91 km) of modelled floodplain edge predicted with seepage in 2050. These additional seepage areas were located near existing seepage areas in the Ral Ral and Pyap-Kingston LWMP areas. There was little difference in the vegetated area predicted to be at salinity risk between the two scenarios in 2050, with an additional 0.2% of the floodplain predicted to be at increased FWIP salinisation risk.

Table 14 shows that the ‘prior commitment’ irrigation claims would lead to an 11,919 m³ d⁻¹ (7.8%) increase in groundwater inflows to the river valley by 2100, compared to the inflows from current irrigation with ‘legacy of history’. This is predicted to lead to a relatively small increase in the total area of vegetation and wetlands at risk of salinisation by 2100 of 306 ha (0.9%). The impacts were greater in terms of seepage risk with a predicted 11 km (9.8%) increase to 123 km of the edge of the modelled floodplain predicted to have seepage, which is almost three times greater than was predicted for the year 2000 under current irrigation and clearing. Figures 30 (Current irrigation and clearing – 2000) and 42 (Prior commitment claims – 2050) show that these seepage areas were located in the Murtho, Ral Ral, Pike River and Gurra Gurra Lakes LWMP areas. Table 14 shows that there was also a significant impact in terms of salt loads to the river and wetlands, with a 132 tonnes d⁻¹ (6.1%) increase predicted by 2100.
Figure 42. Prior commitment claims (2050 and 2100). Map of the locations of the ‘prior commitment’ irrigation claims (and existing irrigation in 2003) in the Chowilla to Lock 3 reach and the resultant inflows to the river valley and the FWIP floodplain and salinisation risk at 2050 and 2100.
Figure 43. Prior commitment claims (2050 and 2100). Map of the locations of the ‘prior commitment’ irrigation claims (and existing irrigation in 2003) in the Lock 3 to Lock 1 reach and the resultant inflows to the river valley and the FWIP floodplain and salinisation risk at 2050 and 2100.
The greater increases in seepage risk and salt loads to the river and wetlands relative to the small increase in the area of vegetation and wetlands at risk of salinisation is related to the location of the ‘prior commitment’ irrigation claims near areas that are currently irrigated and upstream of the nearest weir, e.g. the Murtho, Pike and Taylorville North LWMP areas. In these areas, the floodplain aquifer is already ‘full’, due to the high groundwater inflows from current irrigation and clearing and relatively high river levels. This means that additional groundwater inflows are discharged as seepage at the break of slope and into the river and wetlands. The increases in salt loads to the river may be related to increased groundwater inflows to narrow floodplains (<300 m wide), where most of the groundwater that enters the floodplain is discharged to the river as baseflow.

The FWIP model predicted that 3,695 ha of floodplain vegetation would be at high FWIP salinisation risk under the ‘prior commitment’ irrigation claims (2100) scenario compared to the current irrigation and clearing scenario (2000). This is an additional 4% of the total vegetated floodplain area, increasing from 35.9% in 2000 to 39.6% in 2100 under the ‘prior commitment’ expansion scenario. However, it represents a very small increase (306 ha or 0.4%) in total vegetated floodplain area at risk of salinisation when compared to the current irrigation and clearing scenario (2100). The distribution of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes for current irrigation and clearing (2000) and for the ‘prior commitment’ expansion scenario are summarised in Table 15.

Table 15. Prior commitment claims (2100) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes for current irrigation and clearing (2000) and for current irrigation and clearing plus the ‘prior commitment’ irrigation claims (2100).

<table>
<thead>
<tr>
<th>Prior commitment claims (2100) – 70,000 ML d⁻¹ flood</th>
<th>Salinisation risk</th>
<th>Flooding (ML/day)</th>
<th>Current (2000) vegetated area (ha)</th>
<th>Predicted (2100) vegetated area (ha)</th>
<th>Change in vegetated area (ha and %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High High ≤70,000</td>
<td>14,507</td>
<td>17%</td>
<td>15,342</td>
<td>17%</td>
<td>835</td>
</tr>
<tr>
<td>High High &gt;70,000</td>
<td>3,770</td>
<td>4%</td>
<td>3,894</td>
<td>4%</td>
<td>124</td>
</tr>
<tr>
<td>High Medium ≤70,000</td>
<td>1,555</td>
<td>2%</td>
<td>2,014</td>
<td>2%</td>
<td>459</td>
</tr>
<tr>
<td>High Medium &gt;70,000</td>
<td>3,954</td>
<td>5%</td>
<td>5,010</td>
<td>6%</td>
<td>1,056</td>
</tr>
<tr>
<td>High Low ≤70,000</td>
<td>552</td>
<td>1%</td>
<td>561</td>
<td>1%</td>
<td>9</td>
</tr>
<tr>
<td>High Low &gt;70,000</td>
<td>7,188</td>
<td>8%</td>
<td>7,900</td>
<td>9%</td>
<td>712</td>
</tr>
<tr>
<td>Low High ≤70,000</td>
<td>10,604</td>
<td>12%</td>
<td>9,770</td>
<td>11%</td>
<td>-834</td>
</tr>
<tr>
<td>Low High &gt;70,000</td>
<td>2,094</td>
<td>2%</td>
<td>1,969</td>
<td>2%</td>
<td>-125</td>
</tr>
<tr>
<td>Low Medium ≤70,000</td>
<td>9,654</td>
<td>11%</td>
<td>9,196</td>
<td>10%</td>
<td>-458</td>
</tr>
<tr>
<td>Low Medium &gt;70,000</td>
<td>12,679</td>
<td>14%</td>
<td>11,623</td>
<td>13%</td>
<td>-1,056</td>
</tr>
<tr>
<td>Low Low ≤70,000</td>
<td>2,369</td>
<td>3%</td>
<td>2,359</td>
<td>3%</td>
<td>-10</td>
</tr>
<tr>
<td>Low Low &gt;70,000</td>
<td>18,815</td>
<td>21%</td>
<td>18,103</td>
<td>21%</td>
<td>-712</td>
</tr>
<tr>
<td>Total</td>
<td>87,742</td>
<td></td>
<td>87,742</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The FRM predictions for the ‘prior commitment’ irrigation claims in 2100 and a 70,000 ML d⁻¹ flood indicate that an additional 2,236 ha of floodplain vegetation that were in the four low FWIP, medium and low weir pool salinisation risk classes in 2000 were at increased FWIP salinisation risk under the ‘prior commitment’ irrigation claims in 2100. Table 12 in Section 4.3 showed that most of the healthy (40%) and unhealthy (54%) trees were in these four classes. An additional 513 ha (or 3%) of healthy trees and 675 ha (or 3%) of unhealthy trees that were at low FWIP salinisation risk in 2000 were predicted to be at high FWIP salinisation risk in 2100 under the ‘prior commitment’ irrigation claims scenario. Most of these additional vegetated areas at high FWIP salinisation risk in 2100 under the ‘prior commitment’ irrigation claims scenario were above the 70,000 ML d⁻¹ flood. This means that it is more difficult to
ameliorate the additional groundwater discharge associated with the high FWIP salinisation risk in 2100 with increased flooding.

Figure 44 shows an example of the spatial distribution of the areas of healthy and unhealthy trees (45% of the vegetated floodplain) that are in each of the six salinisation risk classes and whether they can be inundated by a 70,000 ML d⁻¹ flood from between Lock 3 and Lock 4. Note that the medium and high weir pool salinisation risk classes have been merged in this figure.

A comparison of Figure 44 (Prior commitment claims (2100) – 70,000 ML d⁻¹ flood) and Figure 38 (Current irrigation and clearing (2000) – 70,000 ML d⁻¹ flood) in Section 4.3 shows that the ‘prior commitment’ irrigation claims (2100) have increased the FWIP salinisation risk on small parts of the floodplain in the Pyap to Kingston LWMP area. There is little difference between the areas with high FWIP salinisation risk in 2100 in Figure 44 (Prior commitment claims (2100) – 70,000 ML d⁻¹ flood) and Figure 41 (Current irrigation and clearing (2100) – 70,000 ML d⁻¹ flood) in Section 4.4. There was a small area on Pyap floodplain near a ‘prior commitment’ claim that was high FWIP salinisation risk in 2100 in Figure 44 under the ‘prior commitment’ irrigation claims scenario, but low FWIP salinisation risk in Figure 41 under the current irrigation and clearing (2100) scenario.
Figure 44. Prior commitment claims (2100) – 70,000 ML d⁻¹ flood. Example of the tree health, flooding and salinisation risk classes between Locks 3 and 4 for 2100. Areas of healthy trees, outside of the 70,000 ML d⁻¹ flood are shown in light green; areas of healthy trees, within the 70,000 ML d⁻¹ flood are shown in dark green; areas of unhealthy trees, outside of the 70,000 ML d⁻¹ flood are shown in orange; and areas of unhealthy trees, within the 70,000 ML d⁻¹ flood are shown in dark orange.
4.5.2 Weir Pool Raising of 0.5 m

As part of the environmental flow policy formulation process in DWLBC, a range of weir manipulation options are being explored. For the purposes of this report, we chose to use a weir pool raising of 0.5 m on top of the maximum possible flow before the weir was removed in October at each weir between Lock 1 and Lock 6 calculated using the FIM as an example scenario (Table 16). This example scenario represents the maximum possible weir pool raising and flow combination that can be achieved with current weir infrastructure limitations. Note that the subject area does not include the area below Lock 1. Table 16 shows that less than a quarter (24%) of the floodplain upstream of Lock 1 was inundated under the weir pool raising scenario, compared to 42% of the floodplain vegetation that was inundated by a 70,000 ML d⁻¹ flood.

Table 16. Weir pool raising scenario. Summary of the flow over the weir, area inundated by weir pool raising, area not inundated by weir pool raising and area inundated by a 70,000 ML d⁻¹ flood for each lock reach.

<table>
<thead>
<tr>
<th>Lock Reach</th>
<th>Flow (ML d⁻¹)</th>
<th>Area inundated by weir pool raising (ha)</th>
<th>Area not inundated by weir pool raising (ha)</th>
<th>Area inundated by a 70,000 ML d⁻¹ flood (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lock 1</td>
<td>44,000</td>
<td>2,347</td>
<td>5,055</td>
<td>3,010</td>
</tr>
<tr>
<td>Lock 2</td>
<td>41,000</td>
<td>1,104</td>
<td>4,858</td>
<td>2,699</td>
</tr>
<tr>
<td>Lock 3</td>
<td>50,000</td>
<td>5,949</td>
<td>13,652</td>
<td>11,255</td>
</tr>
<tr>
<td>Lock 4</td>
<td>43,000</td>
<td>2,360</td>
<td>10,770</td>
<td>5,420</td>
</tr>
<tr>
<td>Lock 5</td>
<td>50,000</td>
<td>3,414</td>
<td>14,863</td>
<td>6,692</td>
</tr>
<tr>
<td>Lock 6</td>
<td>50,000</td>
<td>3,580</td>
<td>11,248</td>
<td>4,309</td>
</tr>
<tr>
<td><strong>Total area</strong></td>
<td><strong>18,755 (24%)</strong></td>
<td><strong>60,446 (76%)</strong></td>
<td><strong>39,242 (42%)</strong></td>
<td></td>
</tr>
</tbody>
</table>

The FRM used the FWIP model predictions from current irrigation and clearing (2000) to predict FWIP salinisation risk. FWIP and weir pool salinisation risk values were unchanged because the weir pool raising scenario is temporary for the duration of the flood and therefore does not affect the river level at entitlement, which was used to calculate both of these salinisation risks. Therefore, this scenario only represents a change to the potential benefits of flooding between the 70,000 ML d⁻¹ flood and the maximum possible weir pool raising scenario.

Figure 45 gives an example of the four data sets that were combined to produce the FRM Salinisation Risk and Flooding Classes for the floodplain area between Lock 3 and Lock 4. Note that the FWIP salinisation and weir pool salinisation risks were not changed, but the weir pool raising scenario shows the area inundated by the raising of Lock 3 by 0.5 m at a 50,000 ML d⁻¹ flow. Table 16 shows that 30% of the floodplain vegetation between Lock 3 and Lock 4 was inundated under this scenario compared to 57% of the floodplain vegetation between Lock 3 and Lock 4 that was inundated by a 70,000 ML d⁻¹ flood. The area inundated by the weir pool raising scenario was concentrated in the area immediately upstream of Lock 3, whereas the 70,000 ML d⁻¹ flood (Figure 36) inundated a much greater proportion of the floodplain, including areas downstream of Lock 4.
Figure 45. Current irrigation and clearing (2000) – Weir pool raising scenario. Input data used to determine FRM salinisation and flooding risk classes, (clockwise from top left) simplified tree health classification; FWIP salinisation risk showing floodplain vegetation, seepage and wetland areas at risk of salinisation from groundwater discharge; weir pool salinisation risk areas where the river level is \( \leq 2.0 \) m, 2.0 to 3.5 m and >3.5 m below the floodplain surface; and areas inundated by the weir pool raising scenario.
Table 17 shows the vegetated area (ha) and proportion of each salinisation risk and flooding class (%) vegetated by healthy trees, unhealthy trees, dead trees, halophytes and non tree species for the current irrigation and clearing (2000) and weir pool raising scenario. Note that the FWIP salinisation and weir pool salinisation risks were not changed.

Table 17. Current irrigation and clearing (2000) – Weir pool raising scenario. Summary of the vegetated area (ha) and proportion of each salinisation risk and flooding class (%) vegetated by healthy trees, unhealthy trees, dead trees, halophytes and non tree species.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Healthy</td>
<td>Unhealthy</td>
<td>Dead</td>
<td>Halophytes</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Healthy</td>
<td>4,119</td>
<td>5,342</td>
<td>1,023</td>
<td>5,326</td>
</tr>
<tr>
<td>% class area</td>
<td>14%</td>
<td>19%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Unhealthy</td>
<td>12,458</td>
<td>15,131</td>
<td>1,511</td>
<td>5,503</td>
</tr>
<tr>
<td>% class area</td>
<td>25%</td>
<td>30%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Dead</td>
<td>4,602</td>
<td>3,229</td>
<td>1,202</td>
<td>3,853</td>
</tr>
<tr>
<td>% class area</td>
<td>23%</td>
<td>26%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Halophytes</td>
<td>6,118</td>
<td>6,700</td>
<td>881</td>
<td>3,496</td>
</tr>
<tr>
<td>% class area</td>
<td>21%</td>
<td>37%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Not Tree</td>
<td>5,858</td>
<td>10,544</td>
<td>451</td>
<td>3,480</td>
</tr>
<tr>
<td>% class area</td>
<td>21%</td>
<td>37%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Total (ha)</td>
<td>13,878</td>
<td>18,154</td>
<td>1,692</td>
<td>8,773</td>
</tr>
<tr>
<td>% total area</td>
<td>84%</td>
<td>89%</td>
<td>3%</td>
<td>84%</td>
</tr>
</tbody>
</table>

The areas that were not inundated by the weir pool raising scenario contain the greatest areas of healthy (13,878 ha or 84%) and unhealthy (18,154 ha or 89%) trees. The healthy and unhealthy trees comprise ~5,000 ha or 26% of the area inundated by the weir pool raising scenario. Most of the area that was inundated by the weir pool raising scenario contained not tree vegetation 10,838 ha or 58%. Inspection of the vegetation codes showed that not tree vegetation in the flooded class was predominantly wetland species (~9,100 ha or 84%). In contrast, the not tree vegetation that was not inundated by the weir pool raising scenario was mostly chenopod and lignum species, which are typical of the more elevated parts of the floodplain. This means that the weir pool raising scenario can deliver flows to ~5,000 ha or 14% of the healthy and unhealthy trees and most of the wetland species (~9,100 ha or 84%) by raising Locks 1 to 6 by 0.5 m at the maximum possible flow.

Figure 46 shows an example of the areas of healthy and unhealthy trees (45% of the vegetated floodplain) that were in each of the six salinisation risk classes and whether they could be inundated by the weir pool raising scenario from between Lock 3 and Lock 4. Note that the medium and high weir pool salinisation risk classes have been merged in this figure. When Figure 46 (Current irrigation and clearing (2000) – Weir pool raising) was compared to Figure 38 (Current irrigation and clearing (2000) – 70,000 ML d⁻¹ flood) the areas of dark green and dark orange (healthy and unhealthy trees where flooding is possible) were reduced.

Table 18 summarises the vegetated area (ha) in each of the 60 tree health, FWIP salinisation risk, weir pool salinisation risk and flooding classes. The pattern of tree health classes in Table 18 was similar to that reported in Table 12 in Section 4.3, however the area inundated by the weir pool raising scenario was about half of that inundated by the 70,000 ML d⁻¹ flood. Therefore, most of the healthy (56%) and unhealthy (63%) trees were in the low FWIP, medium and low weir pool salinisation risk and no flood classes. This means that it is difficult to deliver flows to these trees using weir pool manipulation, despite having used the maximum possible flow and weir pool raising options available.
Figure 46. Current irrigation and clearing (2000) – Weir pool raising scenario. Example of the tree health, flooding and salinisation risk classes between Locks 3 and 4 for 2000. Areas of healthy trees, outside of the 70,000 ML d$^{-1}$ flood are shown in light green; areas of healthy trees, within the 70,000 ML d$^{-1}$ flood are shown in dark green; areas of unhealthy trees, outside of the 70,000 ML d$^{-1}$ flood are shown in orange; and areas of unhealthy trees, within the 70,000 ML d$^{-1}$ flood are shown in dark orange.
Table 18. Current irrigation and clearing (2000) – Weir pool raising scenario. Summary of the vegetated area (ha) in each of the sixty tree health, FWIP salinisation risk, weir pool salinisation risk and flooding classes. The high FWIP salinisation risk results are in the upper portion of the table, while the low salinisation risk classes are in the lower portion of the table.

### Current Irrigation and Clearing (2000) – Weir pool raising scenario

<table>
<thead>
<tr>
<th>FWIP salinisation risk</th>
<th>Healthy tree area (ha)</th>
<th>% Healthy tree area</th>
<th>Unhealthy tree area (ha)</th>
<th>% Unhealthy tree area</th>
<th>Dead tree area (ha)</th>
<th>% Dead tree area</th>
<th>Halophyte area (ha)</th>
<th>% Halophyte area</th>
<th>Not Tree area (ha)</th>
<th>% Not Tree area</th>
<th>Total area (ha)</th>
<th>% total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Flood</td>
<td>717</td>
<td>4%</td>
<td>635</td>
<td>3%</td>
<td>256</td>
<td>10%</td>
<td>723</td>
<td>7%</td>
<td>7,385</td>
<td>26%</td>
<td>9,717</td>
<td>12%</td>
</tr>
<tr>
<td>High No flood</td>
<td>1,256</td>
<td>8%</td>
<td>1,007</td>
<td>5%</td>
<td>311</td>
<td>12%</td>
<td>1,796</td>
<td>17%</td>
<td>1,465</td>
<td>5%</td>
<td>5,836</td>
<td>7%</td>
</tr>
<tr>
<td>High Medium Flood</td>
<td>43</td>
<td>0%</td>
<td>171</td>
<td>1%</td>
<td>26</td>
<td>1%</td>
<td>72</td>
<td>1%</td>
<td>183</td>
<td>1%</td>
<td>496</td>
<td>1%</td>
</tr>
<tr>
<td>High Medium No flood</td>
<td>815</td>
<td>5%</td>
<td>1,267</td>
<td>6%</td>
<td>257</td>
<td>10%</td>
<td>1,218</td>
<td>11%</td>
<td>1,436</td>
<td>5%</td>
<td>4,992</td>
<td>6%</td>
</tr>
<tr>
<td>High Low Flood</td>
<td>15</td>
<td>0%</td>
<td>97</td>
<td>0%</td>
<td>3</td>
<td>0%</td>
<td>87</td>
<td>1%</td>
<td>122</td>
<td>0%</td>
<td>324</td>
<td>0%</td>
</tr>
<tr>
<td>High Low No flood</td>
<td>1,274</td>
<td>8%</td>
<td>2,165</td>
<td>11%</td>
<td>169</td>
<td>7%</td>
<td>1,429</td>
<td>13%</td>
<td>2,351</td>
<td>8%</td>
<td>5,342</td>
<td>7%</td>
</tr>
<tr>
<td>Healthy tree area (ha)</td>
<td>4,119</td>
<td>5%</td>
<td>5,342</td>
<td>7%</td>
<td>1,023</td>
<td>1%</td>
<td>5,326</td>
<td>7%</td>
<td>12,942</td>
<td>16%</td>
<td>28,752</td>
<td>36%</td>
</tr>
</tbody>
</table>

A smaller proportion of healthy (13%) and unhealthy (17%) trees were in the high FWIP, medium and low weir pool salinisation risk and no flood classes. This means that these trees are likely to be at risk of salinisation associated with groundwater discharge, but cannot be flooded by the weir pool raising scenario. Overall, less than 20% of the healthy and

### Current Irrigation and Clearing (2000) – Weir pool raising scenario

<table>
<thead>
<tr>
<th>FWIP salinisation risk</th>
<th>Healthy tree area (ha)</th>
<th>% Healthy tree area</th>
<th>Unhealthy tree area (ha)</th>
<th>% Unhealthy tree area</th>
<th>Dead tree area (ha)</th>
<th>% Dead tree area</th>
<th>Halophyte area (ha)</th>
<th>% Halophyte area</th>
<th>Not Tree area (ha)</th>
<th>% Not Tree area</th>
<th>Total area (ha)</th>
<th>% total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Flood</td>
<td>1,308</td>
<td>8%</td>
<td>801</td>
<td>4%</td>
<td>460</td>
<td>18%</td>
<td>685</td>
<td>6%</td>
<td>1,862</td>
<td>6%</td>
<td>5,116</td>
<td>6%</td>
</tr>
<tr>
<td>Low No flood</td>
<td>1,320</td>
<td>8%</td>
<td>785</td>
<td>4%</td>
<td>175</td>
<td>7%</td>
<td>649</td>
<td>6%</td>
<td>1,095</td>
<td>4%</td>
<td>4,024</td>
<td>5%</td>
</tr>
<tr>
<td>Low Medium Flood</td>
<td>555</td>
<td>3%</td>
<td>483</td>
<td>2%</td>
<td>91</td>
<td>4%</td>
<td>349</td>
<td>3%</td>
<td>678</td>
<td>2%</td>
<td>2,156</td>
<td>3%</td>
</tr>
<tr>
<td>Low Medium No flood</td>
<td>4,704</td>
<td>28%</td>
<td>4,779</td>
<td>23%</td>
<td>507</td>
<td>20%</td>
<td>1,857</td>
<td>17%</td>
<td>6,770</td>
<td>24%</td>
<td>18,617</td>
<td>24%</td>
</tr>
<tr>
<td>Low Low Flood</td>
<td>61</td>
<td>0%</td>
<td>132</td>
<td>1%</td>
<td>5</td>
<td>0%</td>
<td>140</td>
<td>1%</td>
<td>607</td>
<td>2%</td>
<td>946</td>
<td>1%</td>
</tr>
<tr>
<td>Low Low No flood</td>
<td>4,509</td>
<td>27%</td>
<td>8,150</td>
<td>40%</td>
<td>273</td>
<td>11%</td>
<td>1,823</td>
<td>17%</td>
<td>4,834</td>
<td>20%</td>
<td>19,589</td>
<td>25%</td>
</tr>
<tr>
<td>Healthy tree area (ha)</td>
<td>12,458</td>
<td>16%</td>
<td>15,131</td>
<td>19%</td>
<td>1,511</td>
<td>2%</td>
<td>5,503</td>
<td>7%</td>
<td>15,845</td>
<td>20%</td>
<td>50,448</td>
<td>64%</td>
</tr>
</tbody>
</table>

| Total area (ha)        | 5,116                  | 6%                  | 4,024                    | 5%                    | 2,156              | 3%               | 18,617            | 24%              | 946              | 1%             | 19,589         | 25%           | 50,448         | 64%           |

| % total area           | 6%                     | 5%                   | 3%                       | 24%                   | 1%                 | 25%              | 2%                | 20%              | 1%               | 25%            | 64%           |
unhealthy trees with high FWIP salinisation risk could be inundated by the weir pool raising scenario.

### 4.5.3 Proposed Salt Interception Schemes

The FWIP floodplain salinisation and seepage risk predictions under current irrigation and 'legacy of history' presented in Chapter 5 include the beneficial impacts of the current Woolpunda, Qualco-Sunlands and Waikerie Stages 1 and 2A salt interception schemes. In this example scenario we predict the benefits that may arise from the commissioning of all of the currently proposed salt interception schemes (Waikerie Stages 2B and 2C, Loxton, Bookpurnong, Pike River, Murtho and Chowilla).

To implement this scenario we estimated the average interception efficiencies at 2050 and 2100 for each of the schemes and used these to reduce the inflows to the river valley in the LWMP planning area in which they reside. The FWIP model was then run with these reduced current irrigation and ‘legacy of history’ inflows in 2050 and 2100. The interception efficiencies applied to each of the LWMP areas at 2050 and 2100 were derived from the various MODFLOW models of these schemes and are presented in Table 19. Those for Qualco-Sunlands, Waikerie (Stages 1, 2A, 2B and 2C) and Woolpunda are from Middlemis et al. (2004). Those for Loxton and Bookpurnong are from Yan et al. (2005b). Pike River and Murtho estimates were taken from Aquaterra and REM (2005). Chowilla estimates were taken from Yan et al. (2005a).

#### Table 19. Proposed SIS scenario (2050 and 2100). Summary of the existing and proposed salt interception schemes and their estimated interception efficiencies in 2050 and 2100. The SIS efficiency is the proportion of groundwater inflows at that date that are intercepted by the scheme. The SIS efficiency values of the currently operating schemes at 2000 and 2020 are shown for comparison.

<table>
<thead>
<tr>
<th>Scheme Name</th>
<th>LMWP</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualco-Sunlands</td>
<td>Qualco-Sunlands</td>
<td>0</td>
<td>30</td>
<td>36</td>
<td>39</td>
</tr>
<tr>
<td>Waikerie</td>
<td>Waikerie</td>
<td>51</td>
<td>69</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Woolpunda</td>
<td>Woolpunda</td>
<td>90</td>
<td>90</td>
<td>92</td>
<td>93</td>
</tr>
<tr>
<td>Loxton</td>
<td>Loxton</td>
<td>–</td>
<td>–</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Bookpurnong</td>
<td>Bookpurnong-Lock 4</td>
<td>–</td>
<td>–</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>Pike River</td>
<td>Pike River</td>
<td>–</td>
<td>–</td>
<td>77</td>
<td>89</td>
</tr>
<tr>
<td>Murtho</td>
<td>Murtho</td>
<td>–</td>
<td>–</td>
<td>83</td>
<td>95</td>
</tr>
<tr>
<td>Chowilla</td>
<td>Merriti</td>
<td>–</td>
<td>–</td>
<td>88</td>
<td>88</td>
</tr>
</tbody>
</table>

Figures 47 and 48 show the inflows to the river valley and the predicted FWIP floodplain salinisation and seepage risk at 2050 and 2100 when all of the current and proposed salt interception schemes are fully operational. No results are presented for the Lock 1 to Mannum reach as there are no salt interception schemes proposed for this area. Table 20 provides a summary of FWIP predictions for the years 2050 and 2100 for current irrigation with ‘legacy of history’ and current salt interception schemes, and for current irrigation with ‘legacy of history’ with all salt interception schemes operating.
Figure 47. Proposed SIS scenario (2050 and 2100). Map of the resultant inflows to the river valley and the FWIP floodplain and salinisation risk at 2050 and 2100 as a result of the proposed Chowilla, Murtho, Pike River, Bookpurnong and Loxton salt interception schemes.
Figure 48. Proposed SIS scenario (2050 and 2100). Map of the resultant inflows to the river valley and the FWIP floodplain and salinisation risk at 2050 and 2100 as a result of the current (Qualco-Sunlands, Waikerie Stages 1 and 2A, Woolpunda) and proposed Waikerie 2B and 2C salt interception schemes.
The SIMPACT2 and FWIP model predictions suggest that the implementation of the proposed salt interception schemes would lead to a 44,260 m$^3$ d$^{-1}$ (29.1%) decrease in groundwater inflows to the river valley by 2100. This is predicted to lead to a significant decrease in the area of vegetation and wetlands at risk of salinisation of 9,636 ha (27.9%) by 2100. Similarly, it is predicted that significant reductions (35 km or 31.3%) in the edge of the modelled floodplain with seepage would occur by 2100. It is also predicted that salt loads to the river and wetlands decreases significantly by 811 tonnes d$^{-1}$ (37.5%) by 2100. These predictions suggest that salt interception could be highly beneficial in reducing the salinity risk to the floodplain. However, it should be kept in mind that the large amount of salt stored within the floodplain would need to be removed before the benefits to the vegetation and wetlands could be realised and that the weir pool salinisation risks are unchanged.

Table 20. Proposed SIS scenario (2050 and 2100). Summary of FWIP predictions for the years 2050 and 2100 for current irrigation with ‘legacy of history’ and current salt interception schemes, and for current irrigation with ‘legacy of history’ and all of the current and proposed salt interception schemes operating at the efficiencies detailed in Table 19.

<table>
<thead>
<tr>
<th></th>
<th>Current Irrigation</th>
<th>Proposed SIS Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2050</td>
<td>2100</td>
</tr>
<tr>
<td>Groundwater inflows to the river valley (m$^3$ d$^{-1}$)</td>
<td>108,017</td>
<td>152,274</td>
</tr>
<tr>
<td>Salt load to river (tonnes d$^{-1}$)</td>
<td>1,235</td>
<td>1,678</td>
</tr>
<tr>
<td>Salt load to wetlands (tonnes d$^{-1}$)</td>
<td>390</td>
<td>486</td>
</tr>
<tr>
<td>Salt load to river and wetlands (tonnes d$^{-1}$)</td>
<td>1,625</td>
<td>2,163</td>
</tr>
<tr>
<td>Length of modelled floodplain edge with seepage (km)</td>
<td>86</td>
<td>112</td>
</tr>
<tr>
<td>Total length of edge of modelled floodplain (km)</td>
<td>957</td>
<td>957</td>
</tr>
<tr>
<td>Modelled floodplain edge with seepage</td>
<td>9.0%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on highland side of wetland (ha)</td>
<td>9,988</td>
<td>10,454</td>
</tr>
<tr>
<td>Wetland area at salinity risk (ha)</td>
<td>9,689</td>
<td>9,702</td>
</tr>
<tr>
<td>Vegetation area at salinity risk on river side of wetland (ha)</td>
<td>13,195</td>
<td>14,259</td>
</tr>
<tr>
<td>Total vegetation area on floodplain (ha)</td>
<td>87,742</td>
<td>87,742</td>
</tr>
<tr>
<td>Vegetation and wetlands at salinity risk</td>
<td>37.5%</td>
<td>39.2%</td>
</tr>
</tbody>
</table>

Table 21 shows the distribution of vegetated floodplain area in the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes for groundwater inflows for current irrigation and clearing (2000) and for the current irrigation and clearing with the proposed SIS (2100) scenario. The change in vegetated area for each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes between these two groundwater inflow scenarios is greatest for the high FWIP and low and medium weir pool salinisation risk classes.

Approximately 6,100 ha of vegetated area that was classed as high FWIP salinisation risk under current irrigation and clearing (2000) was classed as low FWIP salinisation risk under the current irrigation and clearing with SIS (2100) scenario. This 6,100 ha of vegetated floodplain area contains approximately 1,500 ha of healthy and unhealthy trees that were classed as high FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing (2000) inflows, but were classed as having a low FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing with SIS (2100) scenario. The 1,500 ha of healthy and unhealthy trees that were classed as having a low FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing with SIS (2100) scenario represent 26% of the healthy and unhealthy trees in the high FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing (2000) inflows. This means that an additional 1,500 ha of healthy and unhealthy trees are at lower salinisation risk due to groundwater discharge in the SIS scenario. However, the time
required to leach salts stored in the soil profile to allow these vegetation communities to recover is unknown.

Table 21. Current irrigation and clearing SIS scenario (2100) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes in comparison to current irrigation and clearing (2000).

<table>
<thead>
<tr>
<th>Salinisation risk FWIP</th>
<th>Flooding (ML d⁻¹)</th>
<th>Current (2000) vegetated area (ha)</th>
<th>SIS scenario (2100) vegetated area (ha)</th>
<th>Change in vegetated area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>≤70,000</td>
<td>14,507 17%</td>
<td>14,484 17%</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>&gt;70,000</td>
<td>3,770 4%</td>
<td>3,781 4%</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>≤70,000</td>
<td>1,555 2%</td>
<td>271 0%</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>&gt;70,000</td>
<td>3,954 5%</td>
<td>2,935 3%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>≤70,000</td>
<td>552 1%</td>
<td>426 0%</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>&gt;70,000</td>
<td>7,188 8%</td>
<td>3,475 4%</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>≤70,000</td>
<td>10,604 12%</td>
<td>10,628 12%</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>&gt;70,000</td>
<td>2,094 2%</td>
<td>2,082 2%</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>≤70,000</td>
<td>9,654 11%</td>
<td>10,939 12%</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>&gt;70,000</td>
<td>12,679 14%</td>
<td>13,698 16%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>≤70,000</td>
<td>2,369 3%</td>
<td>2,494 3%</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>&gt;70,000</td>
<td>18,815 21%</td>
<td>22,527 26%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>87,742</td>
<td>87,742</td>
</tr>
</tbody>
</table>

The comparison between vegetated areas in each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes for groundwater inflows for current irrigation and clearing (2100) and for current irrigation and clearing with SIS (2100) scenario is shown in Table 22. This shows that the greatest reduction in high FWIP salinisation risk occurs in the high FWIP and low and medium weir pool salinisation risk classes. Approximately 8,200 ha of vegetated area that was classed as high FWIP salinisation risk under current irrigation and clearing (2100) was classed as low FWIP salinisation risk under the current irrigation and clearing with SIS (2100) scenario.

This 8,200 ha of vegetation contains approximately 1,050 ha of healthy and 2,500 ha of unhealthy trees that were classed as high FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing (2100) inflows, but were classed as having a low FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing with SIS (2100) scenario. The 3,550 ha of healthy and unhealthy trees that were classed as having a low FWIP and low and medium weir pool salinisation risk using the current irrigation and clearing with SIS (2100) scenario represent 51% of the healthy and unhealthy trees in the high FWIP and low and medium weir pool salinisation risk classes using the current irrigation and clearing (2100) inflows. Most of these trees were in the high FWIP, low weir pool salinisation risk and >70,000 ML d⁻¹ flood class, meaning that despite the change in FWIP salinisation risk from high to low, its chances of rehabilitation were lower because it was in the >70,000 ML d⁻¹ flooding class. A smaller area of vegetation (1,284 ha) was in the high FWIP, medium weir pool salinisation risk and ≤70,000 ML d⁻¹ flood class. The vegetation that was in the high FWIP, medium weir pool salinisation risk and ≤70,000 ML d⁻¹ flood class but is now in the low FWIP, medium weir pool salinisation risk and ≤70,000 ML d⁻¹ flood class has the highest chance of rehabilitation provided some flooding occurs.
Table 22. Current irrigation and clearing SIS scenario (2100) – 70,000 ML d\(^{-1}\) flood. Summary of the vegetated area (ha) in each of the twelve FWIP salinisation risk, weir pool salinisation risk and flooding classes in comparison to current irrigation and clearing no SIS scenario (2100).

<table>
<thead>
<tr>
<th>Salinisation risk FWIP</th>
<th>Weir pool</th>
<th>Flooding (ML/day)</th>
<th>Current (2100) vegetated area (ha)</th>
<th>SIS scenario (2100) vegetated area (ha)</th>
<th>Change in vegetated area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>≤70,000</td>
<td>15,244</td>
<td>14,484</td>
<td>-760</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>&gt;70,000</td>
<td>3,888</td>
<td>3,781</td>
<td>-107</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>≤70,000</td>
<td>1,980</td>
<td>271</td>
<td>-1,709</td>
</tr>
<tr>
<td>High</td>
<td>Medium</td>
<td>&gt;70,000</td>
<td>4,908</td>
<td>2,935</td>
<td>-1,973</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>≤70,000</td>
<td>561</td>
<td>426</td>
<td>-135</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>&gt;70,000</td>
<td>7,834</td>
<td>3,475</td>
<td>-4,359</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>≤70,000</td>
<td>9,868</td>
<td>10,628</td>
<td>760</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>&gt;70,000</td>
<td>1,976</td>
<td>2,082</td>
<td>106</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>≤70,000</td>
<td>9,229</td>
<td>10,939</td>
<td>1,710</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
<td>&gt;70,000</td>
<td>11,726</td>
<td>13,698</td>
<td>1,972</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>≤70,000</td>
<td>2,359</td>
<td>2,494</td>
<td>135</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>&gt;70,000</td>
<td>18,169</td>
<td>22,527</td>
<td>4,358</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>87,742</td>
<td>87,742</td>
<td></td>
</tr>
</tbody>
</table>

Figure 49 shows an example of the areas of healthy and unhealthy trees (45% of the vegetated floodplain) that are in each of the six salinisation risk classes and whether they can be inundated by a 70,000 ML d\(^{-1}\) flood from between Lock 3 and Lock 4. Note that the medium and high weir pool salinisation risk classes have been merged in this figure. A comparison of Figure 49 (Proposed SIS scenario 2100 – 70,000 ML d\(^{-1}\) flood), Figure 38 (Current irrigation and clearing (2000) – 70,000 ML d\(^{-1}\) flood) in Section 4.3 and Figure 41 (Current irrigation and clearing (2100) – 70,000 ML d\(^{-1}\) flood) in Section 4.4 shows that the proposed SIS schemes have reduced the FWIP salinisation risk on the floodplains near the Bookpurnong and Loxton LWMP area downstream of Lock 4. However, the areas with high FWIP salinisation risk upstream of Lock 3 and Lock 4 are unchanged. The area on Pyap floodplain that was low FWIP salinisation risk in 2000, but high FWIP salinisation risk in 2100 is not affected by the proposed SIS schemes.

In summary, the FRM identified 1,500 ha of healthy and unhealthy trees that were at low FWIP salinisation risk under the proposed SIS scenario (2100) in comparison to current irrigation and clearing (2000). When the data from current irrigation and clearing (2000) were compared to the proposed SIS scenario (2100), 3,550 ha of healthy and unhealthy trees were at low FWIP salinisation risk. This means that the proposed SIS scenario (2100) could benefit over 3,500 hectares of healthy and unhealthy trees. However, most of this vegetation was outside of a 70,000 ML d\(^{-1}\) flood, which means that it may be more difficult to remove salts stored in the soil profile in the absence of large floods (>70,000 ML d\(^{-1}\)).
Figure 49. Proposed SIS scenario (2100) – 70,000 ML d⁻¹ flood. Example of the tree health, flooding and salinisation risk classes between Locks 3 and 4 for 2100. Areas of healthy trees, outside of the 70,000 ML d⁻¹ flood are shown in light green; areas of healthy trees, within the 70,000 ML d⁻¹ flood are shown in dark green; areas of unhealthy trees, outside of the 70,000 ML d⁻¹ flood are shown in orange; and areas of unhealthy trees, within the 70,000 ML d⁻¹ flood are shown in dark orange.
5 Limitations of the Models

While considerable effort has been made to address the major limitations of the original FIP model, and improvements/additions have been made to the other component models of the FRM, there are still important limitations to the FRM that need to be acknowledged. Most of the unresolved limitations stem from the simplifying assumptions that were made in order to implement and apply the methodology at the scale of the whole South Australian floodplain. At this scale, the extremely limited groundwater and soil data means that relatively simple analytical and empirical methodologies were adopted in the FRM. This means that the complexity of the hydrogeology and geomorphology of the floodplain has not been represented in the detail that is possible in more complex (but much more data intensive) floodplain models such as WAVES and WINDS (Overton and Jolly, 2004) or MODFLOW-2000 (Doble, 2004). Similarly, the complexities of the hydrogeology and the irrigation/drainage processes in the highland areas have been simplified in SIMPACT2 in order for it to be applied on such a large scale.

For these reasons it is important to understand that the FRM is a rapid assessment approach only. In no way does it replace more detailed modelling of groundwater discharge and leaching of salt from floodplain soils or the complex MODFLOW models of the highland areas. While testing has been carried out against Run-of-River salinity data and other modelling results in order to assess model behaviour, it is not designed as a tool for predicting river salinity. The value of the FRM is as a means of identifying areas of the floodplain which appear to be a priority for risk management, or where there are opportunities for management of existing risk. Some examples may include the identification of areas where:

- irrigation is likely to result in a groundwater salinisation risk to an area of floodplain;
- irrigation is not likely to result in a groundwater salinisation risk to an area of floodplain;
- combined threats, such as irrigation development, weir pool levels and natural groundwater inflows result in a groundwater salinisation risk to an area of floodplain; and
- collection of detailed data, modelling and analysis is likely to be required to support decision making.

The FRM can also be applied as a policy or planning support tool to explore the implications of policy decisions, for example irrigation expansion and SIS on floodplain vegetation. Within this context, the major outstanding limitations of each of the component models in the FRM are described below.

5.1 FIM

The FIM is a steady-state model that predicts the extent of flooding from a given flow on the first day of the flood. It does not consider the effect of antecedent conditions or the effect of flood duration. Further research on the wetting and drying behaviour of the floodplain and its wetlands needs to be incorporated into the model to be able to predict time sequences for management scenarios.

The FIM is based on static remote sensing images taken at a range of river flows. As such, the areas of inundation that are derived from these images represent the flooding behaviour under the floodplain and wetland management conditions at the time of the imagery. Changes in elevations due to subsequent construction of levee banks and regulators, or any other engineering works that alter flow paths in the floodplain and in wetlands, will cause changes in the area of inundation and these are not modelled by the FIM.
Lack of suitable imagery for River Murray flows above of 102,000 ML d\(^{-1}\) means that this is the maximum flow that FIM can model. The approximate floodplain elevations that can be derived from the model can therefore not be determined in areas which require a flow of greater than 102,000 ML d\(^{-1}\) for inundation.

5.2 SIMPACT2

Calculation of flux increases to the river valley is subject to a number of accuracy and limitation issues. Firstly, root zone drainage rates applied are not and to a degree cannot be validated, particularly for very old irrigation. While an attempt has been made to account for improvements in efficiency around the 1980s, no temporal variation in root zone drainage is able to be accommodated at this stage.

Secondly, root zone drainage rates for the Ral Ral, Berri-Barmera and Pyap-Kingston LWMP areas need to be re-assessed in the light of the extremely high inflows predicted for these areas. In the case of Ral Ral and Berri-Barmera, it is thought that this was because these areas have Comprehensive Drainage Schemes and so the root zone drainage rates used in SIMPACT2 are probably overestimates. There is currently a detailed review of drainage re-use and salt interception being carried out in DWLBC (John Rolls, pers. comm.) which may shed some light on this issue. The reasons for the excessive inflows for Pyap-Kingston are unclear but it may be because the estimated root zone drainage rates used in SIMPACT2 are too high for the large areas of old irrigation in this LWMP area. Further investigation is required.

Finally, the predictions are subject to the accuracy of the input layers such as thickness of Blanchetown Clay, aquifer diffusivity, depth to groundwater, salinity of groundwater etc. Each of these are considered the best available and have been accredited for use by the MDBC. However some layers are a legacy of the original version of SIMPACT (Miles et al., 2001). Substantial new drilling has been carried out in many areas in the intervening period and so there may be a need to review some of the input layers in the light of this new information. This became clear during the process of adjusting the pre-irrigation/clearing inflows when it was observed that in some areas the groundwater salinity values in SIMPACT2 were higher than observed in local bores.

The lateral distribution method is also subject to some limitations. Firstly, the extent of lateral distribution is diminished as described in Section 3.5 where 100% of flux is accounted for within ‘6a’ of the central discharge point instead of ‘>20a’. However, considering that the bulk of impacts occur in the vicinity of the central discharge point, it was thought that the resultant predictions of floodplain salinisation risk were not compromised greatly by this approximation.

Secondly, where the geometry of the river is such that there is more than one ‘closest point on the discharge edge’, it is possible that the URE is under estimating fluxes. This is because the URE assumes all impacts are in the one direction towards a straight discharge edge. Using the example in Figure 50 below, it can be seen that 2 areas of discharge can occur within ‘2a’ (red circle on the right) of the one grid cell. This example illustrates grid cell centroids that exhibit recharge at some point in time. The lateral distribution method processes each of these in turn and then aggregates the discharges to floodplain divisions. For explanation of this limitation we will focus on a single grid cell centroid (point R). Point R is the source of recharge, and CDP is the central discharge point. The red circle on the left shows the area of lateral distribution along the floodplain where the model shows that 88% of the discharge is expressed (i.e. a distance of ‘2a’ in both directions). The URE assumes an infinite distance behind the recharge source, so if there is in fact a discharge area in another direction (e.g. D2) than towards the CDP, the total flux discharging to the floodplain will be underestimated. A pragmatic definition of this situation is that the total discharge to the floodplain will be underestimated if there is an area on the discharge edge that is within ‘2a’ radius of the recharge source (red circle on right), yet further than a ‘2a’ radius of the CDP (red circle on left). Further research has been initiated to develop a method to quantify the
underestimate (Glen Walker and David Rassam, CSIRO Land and Water, pers. comm.) however it has not yet been performed on the study area. In estimating the magnitude of this limitation, it is noted that this situation only occurs on 'inside bends' of the floodplain and for grid cells that lie in a particular distance/geometry combination. Except in reaches where inside bends are tight (and these are very few) this combination appears to occur mainly for cells at some distance from discharge locations and therefore has relatively lower flux increases.

Figure 50. Example of a situation where there is a possibility of two discharge locations to the river valley. The total discharge to the floodplain will be underestimated if there is an area on the discharge edge (D2) that is within ‘2a’ radius of the recharge source R (red circle on right), yet further than a ‘2a’ radius of the CDP (red circle on left).

5.3 FWIP

In areas where there has not been significant clearing and irrigation development, the spatial distributions of groundwater inflows to the river valley are dominated by the pre-irrigation/clearing fluxes. As discussed in Section 3.6, these were estimated using Darcy’s Law applied at the FIPRU scale, which can in some cases be very large (such as the one that encompasses the entire Merriit LWMP area which includes the Chowilla and Calperum floodplains). In these situations the FWIP model predictions of floodplain and salinisation risk could be improved by using better local information on inflows such the recently completed Chowilla groundwater model (Yan et al., 2005a). However, in the case of Chowilla the FRM should not be used in preference to more detailed WINDS modelling (Overton and Jolly, 2004).

The mathematics underlying the FWIP model assumes that the floodplain is horizontal and flat. This assumption may lead to under-estimation of evapotranspiration in low lying areas and over-estimation in more elevated areas. Moreover, the spatial scale of the divisions is such that this fine detail cannot be represented. However, at the whole floodplain scale the evapotranspiration predictions represent average values that appear reasonable when compared with published data. On the other hand, if the floodplain is sloping then the model will not accurately predict whether or not seepage at the break of slope will occur, particularly where there are low lying areas in the vicinity of the break in slope. Furthermore, field observations of floodplain geomorphology have suggested that seepage might be associated with floodplain aquifer thinning near backwaters (Banks, 2003). There is insufficient floodplain geomorphological data at the regional scale to identify locations where this may occur and so it is not modelled in FWIP.
The Floodplain Risk Methodology (FRM)

The FWIP model is also limited by lack of data on spatial distribution of floodplain aquifer depths and hydraulic conductivities and so these are set to constant values in the model. It is known from the limited available field data that there is considerable variation in these parameters within the floodplain but the data are too sparse to map this variability reliably. The aquifer parameters used in the model are consistent with average measured values. As further floodplain hydrogeological investigations progress, particularly in relation to salt interception schemes, these values can be updated.

Lack of sufficient data to enable the mapping of groundwater salinity in the floodplain aquifer affects the FWIP model predictions in two ways. Firstly, predictions of salt loads to the river that were used to test the model used SIMPACT2 highland groundwater salinities. This is not an unreasonable assumption given that all salt entering the floodplain must ultimately be discharged to the river under steady-state conditions. However, groundwater salinities in the floodplain aquifer in some areas may be diluted due to backflow from the river or by recharge of floodwaters (example of these are the ‘Flushed Zone’ and ‘Garden of Eden’ at Chowilla; see Overton and Jolly, 2004) and so the model may over predict the salt loads to the river in some locations. Secondly, the FWIP predictions of floodplain salinisation risk are based on the assumption that the risk is due to high groundwater discharge as evapotranspiration through the floodplain. This is true for most areas of the floodplain underlain by saline groundwater, where groundwater discharge as evapotranspiration causes salt to accumulate in the soil profile. However, in areas underlain by low salinity groundwater salt accumulation may be lower, and thus the model may overestimate the risk of salinisation in these areas. Similarly, the FWIP model does not incorporate spatial variations in soil type due to lack of soil/geomorphological mapping for most of the floodplain. Soil texture has a strong influence on groundwater discharge and hence soil salinisation risk. This is not presently accounted for in the model.

FWIP is a steady-state model, and so it is implicitly assumed that the interval between each of these times is large enough for the floodplain to come to a new salinity equilibrium with those inflows. It is known from studies of floods in the Chowilla floodplain (Jolly et al., 1994) that the floodplain water tables hydraulically adjust to new boundary conditions very quickly, usually within weeks or months. The resultant changes in salt accumulation in soils are more likely to occur over the scale of years. As shown by Jolly et al. (1993) and Thorburn et al. (1995), salt usually accumulates to levels resulting in serious tree health decline within 5-20 years, depending on the soil type, groundwater depth and salinity, and flooding regime. The minimum time gap of 20 years used for applying FWIP therefore seems generally reasonable, but it is not guaranteed that there are not some areas of the floodplain where salt accumulation occurs more slowly. In the absence of spatial information on soil types, groundwater depth and salinity it is not possible to identify where this may be an issue.

There is little information of the interactions between wetlands and groundwater and this has posed difficulties in selecting values for the wetland leakage parameter ($\beta$). This model parameter represents the hydraulic conductivity of the soil layer between the wetland and the groundwater multiplied by the width of the wetland along the division flowpath and by the thickness of the soil layer. This is known to vary spatially, however there are little data available. Therefore, as a result of the model testing a constant value of either 10 or 65 m d$^{-1}$ was assumed for divisions with wetlands. This can be modified when better data becomes available. Where there is no wetland, this value is set to zero.

### 5.4 FRM

As described above, data limitations at the regional scale mean that each of the component models/methods have a number of simplifying assumptions that lead to uncertainties in their predictions. These uncertainties become compounded when the component models are used together in the FRM. Whilst it is difficult to exactly specify the scale at which the results are applicable, it is thought that the predictions should be interpreted at a scale of a typical floodplain unit or about 10-15 divisions.
However, as discussed in Section 5.3, in areas where there has not been significant clearing and irrigation development, the spatial distributions of groundwater inflows to the river valley are dominated by the pre-irrigation/clearing inflows which have been estimated at the FIPRU scale. In some instances the FRM results may need to be interpreted at a much larger scale and so caution should be exercised. The Merriti LWMP area, which includes the Chowilla and Calperum floodplains, is a particularly notable example of this situation as it has ~150 divisions in a FIPRU that encompasses the entire LWMP area. Other areas where this may be an issue are Kataraptko Island and the Spectacle Lakes floodplains in the Berri-Barmera LWMP area, and the Moorundie floodplains in the Lock 1 to Mannum LWMP area.

The FWIP salinisation risk classes are transferred to the FRM based on the vegetation polygons location relative to the wetland. This means that if the FWIP model predicts that there is any groundwater discharge in that part of the floodplain then the vegetation polygon is assigned a high FWIP risk. However, only a small portion of that part of the floodplain may have groundwater discharge through it, meaning that the number of vegetation polygons with high FWIP salinisation risk may be over estimated. This is somewhat overcome by the use of a probability when calculating the area of vegetation in each class at high risk as described in Section 4.1.

The weir pool salinisation risk classes rely on the area weighted difference between the river level at entitlement and the floodplain surface from the FIM being calculated for each vegetation polygon. The errors involved in this calculation include the accurate representation of the elevation of the river level at entitlement, which was calculated spatially based on the shortest distance to a river and creek kilometre marker from the centroid of the vegetation polygon. The issues associated with using the area weighted differences between the river level at entitlement and the floodplain surface from the FIM are similar to those for calculating the area weighted flow using the FIM above. The values used to separate the high, medium and low weir pool salinisation risk classes as described in Section 4.1 are based on assumptions about the relationship between soils that are considered typical of the lower River Murray floodplain. However, more detailed analysis may identify better values, or if soil mapping is completed then a range of values for the different soil types could be used.

The FRM uses area weighted flows to determine whether a vegetation polygon is inundated by a specified flow, e.g. 70,000 ML d\(^{-1}\) flood. The use of an area weighted flow is based on the assumption that floodplain vegetation grows in defined area that are related to flooding and soil type, meaning that each vegetation polygon should be located within a reasonably small flow band. However, other factors affect vegetation distribution, including recharge mechanisms and groundwater salinity patterns. This means that a vegetation polygon may include very low flows e.g. 10,000 ML d\(^{-1}\) flows and very high flows e.g. >100,000 ML d\(^{-1}\) flows, meaning that the area weighted average flow does not accurately represent the flooding conditions of that vegetation polygon. This is likely to occur where the river and creeks have cut into the edge of the floodplain. Similarly, the flooding class for the weir pool raising scenario relies on the selection of vegetation polygons based on whether the flooded areas in the weir pool raising scenario layer have their centre in the vegetation polygon. This dataset could be improved with further discretisation of the vegetation polygons to better match the distribution of the flooded area.
6 Conclusions

6.1 FWIP

The mathematics of the original FIP (Floodplain ImPacts) model was successfully upgraded to account for the effects of floodplain backwaters, such as wetlands, anabranches and oxbows (one per floodplain division). The new mathematics was then implemented within ESRI ArcGIS 8 and this new floodplain and wetland salinisation risk tool is referred to as the FWIP (Floodplain Wetland ImPacts) model. The key input to the FWIP model, the groundwater inflows to the river valley for current irrigation/clearing conditions and those arising from future irrigation scenarios, were derived from SIMPACT2. In order to do so, new data and utilities designed to account for the ‘legacy of history’ of existing irrigation that had yet to lead to increased groundwater inflows to the river valley, and the lateral distribution of these inflows along the highland/floodplain edge, were developed for SIMPACT2. Due to the large time delays between commencement of an irrigation development and the resultant inflow of groundwater to the floodplain, predictions of groundwater inflows to the floodplain were made at several reporting times, namely 2000 (representing current conditions), 2020, 2050 and 2100. Accordingly, the FWIP predictions of floodplain and wetland salinisation risk were made at these same reporting times. As FWIP was a steady-state model, it was assumed that the intervals between the reporting times were sufficiently large for the floodplain to come to a new salinity equilibrium in response to the changes in the groundwater inflows.

The FWIP model predicted salinisation risk, seepage areas and salt loads to the river and wetlands in four groundwater inflow scenarios, including the future impacts from 'legacy of history', based on the inflows to the river valley predicted by SIMPACT2 that are discussed below:


The FWIP model predicted that 36% of the floodplain vegetation was at high FWIP salinisation risk, which was comparable to the 41% of the DEH vegetation mapping being classed as unhealthy trees, dead trees or halophytes. These three classes of vegetation are indicative of floodplain salinisation. The highland side of the wetland contained a greater proportion (53% c.f. 44% on the river side of the wetland) of floodplain vegetation that was indicative of salinisation. This was comparable to the pattern of FWIP model salinisation risk, where 44% of the highland side of the wetland was at high FWIP salinisation risk compared to 23% of the river side of the wetland. Most of the wetlands were predicted to have a high FWIP salinisation risk, whereas the dominant vegetation in the wetlands was herbaceous / wetland species, which is indicative of low salinisation. It is likely that the discrepancy between wetland vegetation classes and FWIP salinisation risk in the wetlands was related to flooding, which was not included in the FWIP model.

Seepage was predicted along 4.4% of the floodplain edge. While there was not a comprehensive dataset to compare the location of observed seepage areas to those that were predicted, many of the predicted seepage areas were adjacent to the irrigation areas and appear to have been correctly predicted. While river salt load prediction was not the primary purpose of the model, it was a useful test of the accuracy of the groundwater inflows and the resultant model predictions. The FWIP model predicted salt loads to the river and wetlands totalling 1,186 tonnes d⁻¹. The patterns of salt loads were comparable to the Run-of-River salinity surveys for the period 1998-2004, but the absolute values were somewhat higher and exceeded the Standard Error (SE) range of the Run-of-River values. They were also higher than the average salt loads for the same period that were predicted by the MSM–BIGMOD model (MDBC, 2005b). This may have been related to the lack of salinity data for the floodplain aquifer, which meant that the groundwater salinities used in SIMPACT2 were adopted, or the absence of large floods that mobilise salt to the river over the past decade.
2. Current irrigation and clearing (2100)

Groundwater inflows to the river valley were predicted to double between 2000 and 2100 from 'legacy of history'. The FWIP model predicted that between 2000 and 2100, the area of floodplain vegetation at high FWIP salinisation risk would increase by 2,889 ha (9.1%), the length of modelled floodplain edge with seepage would increase by 70 km (166.7%) and salt loads to the river and wetlands would increase by 977 tonnes d\(^{-1}\) (82.4%). The location of most of the FWIP salinisation risk areas upstream of the nearest weir and adjacent to existing irrigation areas suggest that these floodplains have limited capacity to discharge more water by evapotranspiration as the groundwater is already within the vegetation rooting depth in many of these areas. Therefore, the majority of additional groundwater inflows that occur between 2000 and 2100 were predicted to be discharged as seepage and as groundwater inflows to the river and wetlands.

3. Irrigation Expansion from Prior Commitments (2100)

The model was used to demonstrate the impact of irrigation expansion using the ‘prior commitment’ claims that could potentially be made by irrigators, but that have not necessarily been approved by DWLBC. In this scenario a 6,780 ha expansion of irrigation between the Border and Lock 1 was simulated to commence in 2010. SIMPACT2 predicted that this would lead to a 7.8% increase in groundwater inflows to the river valley by 2100. The FWIP model predicted that an additional 4% of the total vegetated floodplain area would be at risk of salinisation, increasing from 35.9% in 2000 to 39.6% in 2100 under the ‘prior commitment’ expansion scenario. However, it represents a very small increase (306 ha or 0.4%) in total vegetated floodplain area at risk of salinisation when compared to the current irrigation and clearing scenario (2100). The impacts were predicted to be greater in terms of seepage risk with a predicted 9.8% increase in the edge of the modelled floodplain with seepage, which is almost three times greater than was predicted for the year 2000 under current irrigation and clearing. There was also a reasonably significant impact in terms of salt loads to the river and wetlands, with a predicted 6.1% increase by 2100. The greater increases in seepage risk and salt loads to the river and wetlands relative to the small increase in the area of vegetation and wetlands at risk of salinisation is related to the location of the ‘prior commitment’ irrigation claims near areas where the floodplain aquifer is already ‘full’, due to the high groundwater inflows from current irrigation and clearing and relatively high river levels. This means that additional groundwater inflows are discharged as seepage at the break of slope and into the river and wetlands as salt loads.

4. Proposed Salt Interception Schemes (2100)

The final scenario predicted the benefits that may arise from the commissioning of all of the currently proposed salt interception schemes (Waikerie Stages 2B and 2C, Loxton, Bookpurnong, Pike River, Murtho and Chowilla) in addition to the current salt interception schemes (Woolpunda, Qualco-Sunlands and Waikerie Stages 1 and 2A). To implement this scenario we estimated the average interception efficiencies at 2050 and 2100 for each of the schemes and used these to reduce the inflows to the river valley in the LWMP planning area in which they reside. The results from this process suggested that the implementation of the proposed salt interception schemes would lead to a 29.1% decrease in groundwater inflows to the river valley by 2100. This was predicted by the FWIP model to lead to a 27.9% decrease in the area of vegetation and wetlands at risk of salinisation by 2100. Furthermore, it was predicted that a 31.3% reduction in the edge of the modelled floodplain with seepage would occur by 2100. It was also predicted that salt loads to the river and wetlands would decrease by 37.5% by 2100. Overall, the predictions suggested that salt interception could be highly beneficial in reducing the salinity risk to the floodplain and wetland. However, it was noted that the large amounts of salt stored within the floodplain would need to be removed before the benefits to the vegetation and wetlands would be realised.
6.2 FRM

The FRM (Floodplain Risk Methodology) is a rapid assessment approach that brings together our current knowledge of the interactions between salinisation risk associated with groundwater discharge and the benefits of periodic flooding to long term floodplain vegetation health. The FRM combines the outputs of FWIP and FIM (Flood Inundation Model) to identify floodplain areas at risk of salinisation from irrigation development and river regulation, and where they may benefit from periodic flooding and weir pool manipulation. This was done by combining the floodplain and wetland salinisation risks predicted by FWIP, the risk of salinisation from shallow groundwater associated with weir pool levels, the potential benefits of periodic flooding from the FIM with the DEH vegetation floristic and health mapping to produce the FRM. The role of the FRM is:

1. to identify areas where irrigation and weir pool levels increase the risk of salinisation;
2. to prioritise areas for where collection of detailed data, modelling and analysis is likely to be required to support decision making; or
3. as a policy or planning support tool to explore the implications of policy decisions.

While considerable effort was made to address the major limitations of the original FIP model, and improvements/additions were made to the other components of the FRM, there were still important unresolved limitations to the FRM approach. Most of these stemmed from the simplifying assumptions that were made in order to implement and apply the methodology at the scale of the whole South Australian River Murray floodplain. Note that it does not replace more detailed WAVES and WINDS modelling of groundwater discharge and leaching of salt from floodplain soils or the complex MODFLOW models of the highland areas.

While the FRM and its component models were developed for the River Murray floodplain in South Australia, it is likely that they have application further upstream in the River Murray system or to other river systems where salinisation associated with groundwater discharge affects floodplain vegetation health. As part of the CSIRO Water for a Healthy Country Flagship Program (Ecological Outcomes Project), the FIM is presently being extended along the River Murray up to Hume Dam (Oerton et al., 2005). Similarly, SIMPACT (in the form of SIMRAT; MDBC, 2005a) is presently being extended to the Victorian and New South Wales Mallee region as part of MDBC Interstate Water Trading Project and the CSIRO Water for a Healthy Country Flagship Program (Lower Murray Futures Project). In principle, the FWIP model could also be extended into this region. However, the more complex floodplain hydrogeology and land uses that exist in parts of this region may act as an impediment to its application there, or at the very least require some modifications to the approach to account for these issues.

The first step in the development of the FRM was to combine the broadscale ‘FWIP salinisation risk’ with the finer scale ‘weir pool salinisation risk’. ‘Weir pool salinisation risk’ is the depth of the water table due to river level alone. However, ‘weir pool salinisation risk’ does not take into account areas of the floodplain where the water table is above river level, such as areas adjacent to irrigation mounds. Therefore, while it is a finer scale assessment, it may be an underestimate of floodplain salinisation risk. For each scenario, the 32,000 vegetation polygons along the whole of the South Australian River Murray floodplain were assigned one of six possible salinisation risk classes (high or low FWIP salinisation risk and high, medium or low weir pool salinisation risk). These six salinisation risk classes can be grouped into three management scenario:

1. **Salt Interception Scheme (SIS) to control groundwater inflows**
   These areas were at high FWIP salinisation risk, but had medium to low weir pool salinisation risk. This suggests that they may benefit from salt interception to reduce the volume of groundwater inflows, thus reducing the rate of groundwater discharge.
and salinisation risk. Some of these areas may be within the more frequent small to medium sized floods, making flow management possible.

2. **Protect from future salinisation risks**

These areas were at low FWIP salinisation risk and had medium to low weir pool salinisation risk. This means that increases in groundwater inflows in the future from new developments and/or ‘legacy of history’ may threaten these areas. Some of these areas may be within the more frequent small to medium sized floods, making flow management possible.

3. **Limited management options available**

These areas had a high weir pool salinisation risk. Therefore, it is likely that floodplain groundwater levels in these areas would be difficult to manage because they are close to river level. However, being low in the landscape, it is likely that if the groundwater is relatively fresh then they are vegetated by healthy trees, whereas if the groundwater is more saline, then they may be vegetated by halophytes.

The next step in the development of the FRM was to define flooding classes. To do this, the extent of the present-day ‘active’ floodplain was determined based on the return period (1 in 7 years) of a flow that inundated ~95% of the Red Gum and Black Box communities on the Chowilla floodplain under natural conditions. Under current conditions this recurrence interval is equivalent to a flow of ~70,000 ML d⁻¹, which is also the maximum flow for which viable engineering options can be used to ‘water’ the floodplain. Therefore, a 70,000 ML d⁻¹ flow or less that defines the ‘active’ floodplain and represents a critical ecological and engineering threshold in the lower River Murray in South Australia.

The FRM was applied to five scenarios, including three examples of the types of scenarios that demonstrate the way in which the methodology could be applied to examine the impacts and benefits of potential management options. The results of these five scenarios are summarised below:

**6.2.1 Current irrigation and clearing (2000) and a 70,000 ML d⁻¹ flood**

The FRM showed that over three quarters of the healthy and unhealthy trees were located in the low FWIP salinisation risk class, in comparison to only 64% of the entire vegetated area (Table 23). Most of these trees were in the medium to low weir pool salinisation risk, but were outside of the 70,000 ML d⁻¹ flood. These classes are a priority for protection from future salinisation risks. There were a greater proportion of healthy than unhealthy trees in the low FWIP, medium to high weir pool salinisation risk and ≤70,000 ML d⁻¹ flood class, which may be related to the more frequent flooding of these areas and it may also indicate that the groundwater in these areas is relatively fresh. Most of the halophytes were in the low lying parts of the landscape with a medium to high weir pool salinisation risk (72%). The FWIP and weir pool salinisation risk classes were able to distinguish between the two dominant not tree vegetation types. Chenopods (72%) dominated the not tree vegetation in the high FWIP, high weir pool salinisation risk and >70,000 ML d⁻¹ flooding class, whereas lignum was dominant in the low FWIP salinisation risk areas. A strong relationship between flooding and weir pool salinisation risk, which are both were related to floodplain elevation and river levels was observed.
Table 23. Current irrigation and clearing (2000) – 70,000 ML d⁻¹ flood. Summary of the area vegetated by healthy trees, unhealthy trees and other vegetation (ha) in the three management scenarios for each flooding class.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Healthy trees area (ha)</th>
<th>Healthy trees %</th>
<th>Unhealthy trees area (ha)</th>
<th>Unhealthy trees %</th>
<th>Other vegetation area (ha)</th>
<th>Other vegetation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Interception Scheme (SIS) to control groundwater inflows (High FWIP, medium to low weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>327 2%</td>
<td>3,098 14%</td>
<td>6,216 13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>1,828 10%</td>
<td>608 3%</td>
<td>1,173 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protect from future salinisation risks (Low FWIP, medium to low weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>3,084 17%</td>
<td>2,443 11%</td>
<td>6,497 14%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>7,110 40%</td>
<td>11,930 54%</td>
<td>12,454 26%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited management options available (High or Low FWIP, high weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>4,252 24%</td>
<td>2,512 11%</td>
<td>8,206 17%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>1,367 8%</td>
<td>1,447 7%</td>
<td>13,190 28%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>17,968</td>
<td>22,038</td>
<td>47,736</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.2.2 Current irrigation and clearing (2100) and a 70,000 ML d⁻¹ flood

The FRM predictions for current irrigation and clearing (2100) and a 70,000 ML d⁻¹ flood show that most of the increase in vegetated area in the high FWIP salinisation risk class occurs in the medium weir pool salinisation risk class (Table 24). Over 1,300 ha of floodplain vegetation that was at low FWIP, medium weir pool salinisation risk in 2000 was predicted to be at high FWIP, medium weir pool salinisation risk in 2100. Almost 1,000 ha of this vegetation was outside of a 70,000 ML d⁻¹ flood, indicating that it would be difficult to ameliorate the increased FWIP salinisation risk with flooding. This class contained most of the healthy (5,527 ha or 31% of the healthy trees) and unhealthy (5,916 ha or 27% of the unhealthy trees), which means that an additional 700 ha of healthy and unhealthy trees were at greater risk of salinisation due to groundwater discharge associated with current irrigation and clearing in 2100 than in 2000.

Table 24. Current irrigation and clearing (2100) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in the three management scenarios for each flooding class in comparison to the Current irrigation and clearing (2000) scenario.

<table>
<thead>
<tr>
<th>Current (2000) area (ha)</th>
<th>Predicted (2100) area (ha)</th>
<th>Difference area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Interception Scheme (SIS) to control groundwater inflows (High FWIP, medium to low weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>2,541</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>12,742</td>
<td>15%</td>
</tr>
<tr>
<td>Protect from future salinisation risks (Low FWIP, medium to low weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>11,588</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>29,895</td>
<td>34%</td>
</tr>
<tr>
<td>Limited management options available (High or Low FWIP, high weir pool salinisation risk)</td>
<td>≤ 70,000 ML d⁻¹</td>
<td>25,112</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>&gt; 70,000 ML d⁻¹</td>
<td>5,864</td>
<td>6%</td>
</tr>
<tr>
<td>Total</td>
<td>87,742</td>
<td>87,742</td>
<td></td>
</tr>
</tbody>
</table>
6.2.3 Irrigation Expansion from Prior Commitments

The FRM predictions for the ‘prior commitment’ irrigation claims in 2100 and a 70,000 ML d<sup>-1</sup> flood indicate that an additional 2,236 ha of floodplain vegetation that were in the four low FWIP, medium and low weir pool salinisation risk classes in 2000 were at increased FWIP salinisation risk under the ‘prior commitment’ irrigation claims in 2100. An additional 513 ha (or 3%) of the healthy trees and 675 ha (or 3%) of the unhealthy trees that were at low FWIP salinisation risk in 2000 were predicted to be at high FWIP salinisation risk in 2100 under the ‘prior commitment’ irrigation claims scenario. Most of these additional vegetated areas at high FWIP salinisation risk in 2100 under the ‘prior commitment’ irrigation claims scenario were above the 70,000 ML d<sup>-1</sup> flood, which means that it is more difficult to ameliorate the additional salinisation risk with increased flooding.

6.2.4 Weir Pool Raising of 0.5 m

The example weir raising scenario represents the maximum possible weir pool raising and flow combination that can be achieved with current weir infrastructure limitations. The area inundated by raising each weir pool between Lock 1 and Lock 6 by 0.5 m on top of the maximum possible flow before the weir was removed in October was calculated using the FIM. Note that this does not include the floodplain area below Lock 1. FWIP and weir pool salinisation risk values were unchanged because the weir pool raising scenario was temporary for the duration of the flood and therefore does not affect the river level at entitlement, which was used to calculate both of these salinisation risks (Table 25). The weir pool raising scenario inundated less than a quarter (24%) of the floodplain upstream of Lock 1, compared to almost half (42%) of the floodplain vegetation that was inundated by a 70,000 ML d<sup>-1</sup> flood.

Table 25. Current irrigation and clearing (2000) – Weir pool raising scenario. Summary of the area vegetated by healthy trees, unhealthy trees and other vegetation (ha) in the three management scenarios for each flooding class.

<table>
<thead>
<tr>
<th></th>
<th>Healthy trees area (ha)</th>
<th>Healthy trees %</th>
<th>Unhealthy trees area (ha)</th>
<th>Unhealthy trees %</th>
<th>Other vegetation area (ha)</th>
<th>Other vegetation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Interception Scheme (SIS) to control groundwater inflows (High FWIP, medium to low weir pool salinisation risk)</td>
<td>Flood 58 0%</td>
<td>268 1%</td>
<td>493 1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No flood 2,089 13%</td>
<td>3,432 17%</td>
<td>6,860 16%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protect from future salinisation risks (Low FWIP, medium to low weir pool salinisation risk)</td>
<td>Flood 616 4%</td>
<td>615 3%</td>
<td>1,870 4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No flood 9,213 56%</td>
<td>12,929 63%</td>
<td>16,064 38%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited management options available (High or Low FWIP, high weir pool salinisation risk)</td>
<td>Flood 2,025 12%</td>
<td>1,436 7%</td>
<td>11,371 27%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No flood 2,576 16%</td>
<td>1,792 9%</td>
<td>5,491 13%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16,577 20,472 42,149</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most of the area that was inundated by the weir pool raising scenario contained not tree vegetation (10,838 ha or 58%), which was predominantly wetland species (~9,100 ha or 84%). In contrast, the not tree vegetation that was not inundated by the weir pool raising scenario was mostly chenopod and lignum species, which are typical of the more elevated parts of the floodplain. The areas that were not inundated by the weir pool raising scenario contained the greatest areas of healthy (13,878 ha or 84%) and unhealthy (18,154 ha or 89%) trees. This means that the weir pool raising scenario can deliver flows to ~5,000 ha or 14% of the healthy and unhealthy trees and ~9,100 ha of wetland species by raising Locks 1 to 6 by 0.5 m at the maximum possible flow.
The FRM showed that most of the healthy (56%) and unhealthy (63%) trees were in the low FWIP, medium and low weir pool salinisation risk and no flood classes. This means that it is difficult to deliver flows to these trees using weir pool manipulation, despite having used the maximum possible flow and weir pool raising options available. A smaller proportion of healthy (13%) and unhealthy (17%) trees were in the high FWIP, medium and low weir pool salinisation risk and no flood classes. This means that these trees are likely to be at risk of salinisation associated with groundwater discharge, but cannot be flooded by the weir pool raising scenario. Overall, less than 20% of the healthy and unhealthy trees with high FWIP salinisation risk could be inundated by the weir pool raising scenario.

6.2.5 Proposed Salt Interception Schemes

Approximately 8,200 ha of vegetated area that was classed as high FWIP salinisation risk under current irrigation and clearing (2100) was classed as low FWIP salinisation risk under the current irrigation and clearing with SIS (2100) scenario (Table 26). Over 3,500 ha of healthy and unhealthy trees that were predicted to have low FWIP salinisation risk under the proposed SIS scenario (2100) had been classed as high FWIP salinisation risk under the current irrigation and clearing (2100) scenario. This means that the proposed SIS scenario (2100) could benefit over 3,500 hectares of healthy and unhealthy trees. However, most of this vegetation was outside of a 70,000 ML d⁻¹ flood, which means that it may be more difficult to remove salts stored in the soil profile in the absence of large floods (>70,000 ML d⁻¹).

Table 26. Current irrigation and clearing (2100) – 70,000 ML d⁻¹ flood. Summary of the vegetated area (ha) in the three management scenarios for each flooding class in comparison to the Current irrigation and clearing (2000) scenario.

<table>
<thead>
<tr>
<th>Salt Interception Scheme (SIS) to control groundwater inflows (High FWIP, medium to low weir pool salinisation risk)</th>
<th>Current (2000) area (ha)</th>
<th>%</th>
<th>Predicted (2100) area (ha)</th>
<th>%</th>
<th>Difference area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 70,000 ML d⁻¹</td>
<td>2,107</td>
<td>3%</td>
<td>697</td>
<td>0%</td>
<td>-1,410</td>
<td>33%</td>
</tr>
<tr>
<td>&gt; 70,000 ML d⁻¹</td>
<td>11,142</td>
<td>13%</td>
<td>6,410</td>
<td>7%</td>
<td>-4,732</td>
<td>58%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protect from future salinisation risks (Low FWIP, medium to low weir pool salinisation risk)</th>
<th>Current (2000) area (ha)</th>
<th>%</th>
<th>Predicted (2100) area (ha)</th>
<th>%</th>
<th>Difference area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 70,000 ML d⁻¹</td>
<td>25,111</td>
<td>29%</td>
<td>25,112</td>
<td>29%</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>&gt; 70,000 ML d⁻¹</td>
<td>5,864</td>
<td>6%</td>
<td>5,863</td>
<td>6%</td>
<td>-1</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Limited management options available (High or Low FWIP, high weir pool salinisation risk)</th>
<th>Current (2000) area (ha)</th>
<th>%</th>
<th>Predicted (2100) area (ha)</th>
<th>%</th>
<th>Difference area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 70,000 ML d⁻¹</td>
<td>25,111</td>
<td>29%</td>
<td>25,112</td>
<td>28%</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>&gt; 70,000 ML d⁻¹</td>
<td>5,864</td>
<td>6%</td>
<td>5,863</td>
<td>6%</td>
<td>-1</td>
<td>100%</td>
</tr>
</tbody>
</table>

| Total | 87,742 |  | 87,742 |  |
7 Recommendations

The FRM is a rapid assessment approach that brings together our current knowledge of the interactions between salinisation risk associated with groundwater discharge and the benefits of flooding to long term floodplain vegetation health. However, in no way does it replace more detailed modelling of floodplain and wetland salinisation risk and the beneficial effects of improved floodplain inundation and groundwater management.

7.1 Use of the Floodplain Risk Methodology for Management and Policy

As discussed in Section 5.4, limitations of the various regional scale models that are used together in the FRM leads to a degree of uncertainty in the predictions. The uncertainty may be particularly large in some areas where there has not been significant clearing and irrigation development, and hence the spatial distributions of groundwater inflows to the river valley are dominated by the pre-irrigation/clearing inflows which have been estimated at the FIPRU scale. For these reasons the FRM should be considered as a rapid assessment tool whose role is to identify areas where irrigation and weir pool levels increase the risk of salinisation, to prioritise areas for where collection of detailed data, modelling and analysis is likely to be required to support decision making, or as a policy or planning support tool to explore the implications of policy decisions.

Whilst it is difficult to exactly specify the scale at which the results are applicable, it is recommended that:

1. FRM predictions should not be interpreted at a scale of less than about 10-15 divisions, and in areas without significant clearing and irrigation, additional caution should be exercised.

Notwithstanding the identified limitations of the FRM, it is the only methodology available for the whole of the River Murray floodplain in South Australia. As such, the FRM and the data sets contained within could be used to assist in the evaluation and reporting against resource condition targets and other aspirational goals contained within the various River Murray initiatives such as the RMWAP, MDBC Living Murray, and Floodplain Planning etc. It is therefore recommended that:

2. RMCWMB and DWLBC, in consultation with CSIRO Land and Water and DEH, explore and develop the role that the FRM can play in assisting the evaluation and reporting against the goals of the various River Murray initiatives aimed at protecting and improving the health of the floodplain.

The development of the FRM and the data sets contained within has been a joint effort between CSIRO Land and Water and DEH. The primary user however is the River Murray policy makers and managers within DWLBC and RMCWMB/Murray Darling Basin NRM Board. As such planning for the transfer of the technology needs to take place. It is therefore recommended that:

3. consultation between the potential users DWLBC, RMCWMB/ NRM Board, CSIRO Land and Water and DEH take place to resolve the long-term custodianship of the FRM and its data sets in a manner that ensures adequate training of users and the ability to update the data and improve the component models within the FRM as new information becomes available.

7.2 Outstanding Technical Issues

As described in Chapter 4, obtaining groundwater inflows to the river valley under current conditions with ‘legacy of history’ was a difficult process. For methodological consistency over the entire study area, and for consistency with current salinity policy development, we
chose to use SIMPACT2 for this purpose. However, due to some of the limitations of SIMPACT2 described in Chapter 8, it was necessary to make adjustments to the predicted inflows as they appeared unrealistically high in some LWMP areas. Furthermore, in estimating the pre-irrigation/clearing inflows there were no historical data with which to check our estimates, and so these were also adjusted at the large FIPRU scale to help provide what we felt were realistic predictions of salinisation risk by the FWIP model. In carrying out these adjustments we referred to all of the previous studies that had attempted to predict or estimate inflows. It was very clear that there are considerable inconsistencies between the studies, as highlighted in Table 5. One observation of particular concern was the preponderance in some studies for selectively using groundwater salinity data or manipulating the inflows to match measured river salinity data. It is therefore recommended that:

4. a project be established to review in detail all previously published studies, along with all recent highland drilling, geophysics and modelling results, in order to derive an agreed spatial data set of inflows to the river valley for current conditions with 'legacy of history'. Once completed, this data set should be adopted for the FRM.

In incorporating the salinisation impact on wetlands in FWIP it is necessary to estimate the wetland leakage parameter ($\beta$) for each of the wetlands represented in the model. In the absence of any data in almost all cases we used two different constant values which were selected on the basis of which appeared to provide the most realistic salinity risk prediction from the FWIP model. While the lack of knowledge and data will be assisted by new projects such as the Centre for Natural Resources (CNRM) Project 17 (Surface Water - Groundwater Interactions in River Murray Wetlands and Implications for Water Quality and Ecology), there is an on-going need to build the data base for all major wetlands, particularly those where water regimes are being manipulated. It is therefore recommended that:

5. for all current and future wetlands that have their water levels manipulated, studies are carried out to determine the leakage relationship between the wetland and the underlying groundwater.

Another shortcoming in the implementation of the FWIP model was the need to assume constant floodplain aquifer depths and hydraulic conductivities due to an absence of sufficient data in which to map these parameters spatially. Similarly, there is a lack of floodplain groundwater salinity data which is also an important parameter needed for predicting floodplain and wetland salinisation risk. However, it is probable that this situation will improve over time as floodplain drilling proceeds as part of various salt interception scheme and wetland management investigations. At the beginning of the "Assessing Current and Future Impacts of Land Management Induced Groundwater Discharge on Floodplain Health" project a collation of all floodplain groundwater data was carried out by DWLBC (Steve Barnett). It is important to ensure that all groundwater data from recent and future floodplain investigations are continually incorporated into this collation and made available to all parties carrying out floodplain investigations. It is therefore recommended that:

6. the current DWLBC repository of floodplain groundwater data is reviewed to ensure that it contains all data from recent investigations, and when all missing data has been collected and collated, the existence of the data should be communicated and provided to all parties involved in floodplain investigations. Further, a protocol should be established to ensure that all future floodplain groundwater data are incorporated in the repository and updates provided to all interested parties.

As discussed at the beginning of Chapter 8, many of the unresolved limitations of the FRM are controlled by the limited spatial hydrogeological and geomorphological data at the regional scale. As described above, it is likely that there will be future groundwater
investigations that will greatly improve the hydrogeological data sets over time. However, there are presently no plans for the mapping of the geomorphology and soils for the whole floodplain in South Australia. At present these maps are only available for the Chowilla floodplain and some parts of the Murtho and Pike River floodplains. This is a serious impediment to improving the floodplain and wetland salinisation risk methods, in particular the application of models such as WINDS, WAVES and new MODFLOW-2000 methods that can provide predictions at a finer scale than the present FRM. The lack of this mapping is also a serious impediment to developing methodologies for predicting the river salinity disbenefits of improved inundation of the floodplain using environmental flows, weir pool raising and other water delivery methods. These are needed for river salinity accountability under agreements such as the MDBC Basin Salinity Management Strategy (MDBC 2003). It is therefore recommended that:

7. geomorphological/soil type mapping be completed for the entire floodplain in South Australia using an approach and scale consistent with the existing mapped areas described above.

As described in Section 3.4, in order to apply the analytical cross sectional model spatially in FWIP the floodplain was divided into ~3000 representative cross sections referred to as divisions. These represent the expected groundwater flow path across the floodplain, and in the absence of sufficient floodplain groundwater data, were defined based on the floodplain geometry. It is thought that they are generally sound. However, as more floodplain groundwater data are collected over time it will be possible to prepare reliable maps of floodplain groundwater levels and hence more accurate flow paths across the floodplain. In some instances it may be necessary to alter the shape and sizes of the divisions to account for this new information. It is therefore recommended that:

8. as new floodplain groundwater data are collected and transferred into the DWLBC repository, efforts are made to produce floodplain groundwater level maps for floodplains once sufficient data are available, and that these are made available to the developers/custodians of the FRM so that modifications to the FWIP model can be made if required.

Similarly, as described in Section 5.2 there are still some outstanding geometrical issues in SIMPACT2 with respect to how highland groundwater flows arising from irrigation developments are distributed laterally along the discharge edge in reaches where inside bends are tight. While some further work has been initiated by CSIRO Land and Water to quantify the magnitude of the underestimate in inflows to the river valley that may be caused by this issue, it is not yet a formal project in relation to the FRM study area. It is therefore recommended that:

9. a formal funded project should be initiated to resolve the outstanding geometric issues in SIMPACT2 in relation to the lateral distribution of inflows to the river valley in the FRM study area.

The FRM was developed to be used as a rapid assessment tool, whose roles include the identification of areas where irrigation and weir pool levels increase the risk of salinisation, to prioritise areas where the collection of detailed data, modelling and analysis is likely to be required to support decision making, or as a policy or planning support tool to explore the implications of policy decisions. Based on the current level of knowledge and long history of detailed investigation at Chowilla, it is recommended that:

10. the FRM should not be used in areas such as Chowilla which have much more detailed models such as WINDS and WAVES that can be used to assess floodplain salinisation risk and the benefits of improved flooding and groundwater management.
Glossary

**Capillary rise:** the upward movement of groundwater through the soil caused by the surface tension of water in soil pores. When water tables rise to near the surface, drying of soil by evaporation and transpiration leads to high rates of capillary rise of groundwater. This is an important form of groundwater discharge and if the groundwater is saline then this process leads to salt accumulation in the soil profile.

**Dynamic equilibrium:** refers to how a groundwater system/soil hydrology responds to naturally varying rainfall/flooding rather than any land use change. Land use change usually results in a transformation to a new dynamic equilibrium.

**Evapotranspiration:** loss of water to the atmosphere by evaporation from the soil surface and by transpiration from plants.

**Groundwater discharge:** the loss of water from a groundwater system (aquifer) to the atmosphere by evaporation, springs and/or transpiration over a given period.

**Leaching:** the removal of salt from the soil profile by water applied at or near the soil surface (rainfall, floodwater, irrigation). This water drains down through the soil profile taking salt with it.

**Root zone:** the part of the soil profile where plant roots are active.

**Salt accumulation:** when saline water tables rise near to the soil surface evaporation and water uptake by plants leads to a build up of salts left behind in the soil profile.

**Transpiration:** loss of water vapour and other gases from leaves and other plant surfaces to the atmosphere. Also referred to as plant water use or uptake.

**Water table:** the level of groundwater in an unconfined aquifer. The soil pores and geologic strata below the water table are saturated with water.
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The Floodplain Risk Methodology (FRM)


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Gardner, WR & Fireman, M 1958, Laboratory studies of evaporation from soil columns in the presence of a water table, Soil Science, vol. 85. pp. 244-249.


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Appendix A: FWIP Model Mathematics

Assumptions

The following assumptions are made:

1. groundwater flow is one-dimensional, under steady state conditions with no recharge, and the floodplain aquifer is homogenous and isotropic;

2. groundwater flow under the floodplain is defined by Darcy’s Law, where $Q$ is the flux of groundwater ($\text{m}^3\text{d}^{-1}$); $K$ is the floodplain aquifer horizontal hydraulic conductivity ($\text{m d}^{-1}$); $b$ is the floodplain aquifer thickness (m); and $dh/dx$ is the floodplain groundwater hydraulic gradient, where $h$ is the height of the floodplain groundwater level above river level (m) and $x$ is the distance from the edge of the river valley (m) as shown in Figure A1;

$$\frac{dh}{dx} = -Q = -Kb \frac{dh}{dx}$$  \hspace{1cm} (a)

3. loss of groundwater through evapotranspiration is described by a simple linear function, where $ET$ is the rate of groundwater loss through evapotranspiration ($\text{m d}^{-1}$); $a$ is the maximum discharge rate ($\text{m d}^{-1}$); $z_{ext}$ is the evapotranspiration extinction depth (m), below which there is no evapotranspiration; and $h_f$ is the height of the floodplain above river level (m):

$$ET = \frac{a(z_{ext} - h_f + h)}{z_{ext}} \text{ when } h > h_f - z_{ext}$$  \hspace{1cm} (b)

$$ET = 0 \text{ when } h < z_{ext}$$  \hspace{1cm} (c)

4. the shape of the river valley is characterised by a sharp cliff and a flat floodplain; and

5. the wetland is located at a distance $x_w$ (m) from the break of slope (where $0 < x_w < x$). Groundwater flow into or out of the wetland is controlled by the wetland leakage parameter $\beta$ ($\text{m d}^{-1}$) and groundwater levels. Groundwater flow is calculated as the flux to/from the highland side and the flux to/from the river side of the wetland. The flux into or out of the wetland is the difference between these two fluxes.

![Figure A1. Possible model scenarios showing groundwater levels at the highland and wetland and river level relative to the extinction depth ($h^*=z^*$).](image-url)
**Governing Equations**

When the groundwater level is above the extinction depth, groundwater flow is controlled by the hydraulic gradient and evapotranspiration across the floodplain, i.e.

\[
Kb \frac{d^2h}{dx^2} = \frac{a(z_{ext} - h_f + h)}{z_{ext}} \quad \text{when} \quad h > h_f - z_{ext}, \text{ or }
\]

(1a) \[
Kb \frac{d^2h}{dx^2} = 0 \quad \text{when} \quad h < h_f - z_{ext}.
\]

(1b)

The boundary condition at the edge of the floodplain (i.e. \(x=0\)) is given by:

\[
-Kb \frac{dh}{dx} = Q_{in} \quad \text{at} \quad x = 0 \quad \text{when} \quad h < h_f \quad (\text{i.e. no seepage}), \text{ or }
\]

(2a) \[
h = h_f \quad \text{at} \quad x = 0 \quad (\text{i.e. seepage}), \text{ where:}
\]

(2b)

\(Q_{in}\) is the groundwater flux entering the floodplain.

The river represents a constant head boundary condition, therefore:

\[h = 0 \quad \text{at} \quad x = L.\]

(3)

The wetland boundary condition is given by:

\[Q_w = \beta(z_w - h_w) \quad \text{at} \quad x = x_w, \text{ where:}
\]

(4)

\(Q_w\) is the downward leakage from wetland at distance \(x_w\)

\(z_w\) is the height of the water in the wetland above the river at distance \(x_w\)

\(h_w\) is the height of the groundwater beneath/above the wetland at distance \(x_w\).

The difference in flux at each side of the discontinuity at \(x_w\) is equal to the leakage thus:

\[-Kb \left(\frac{dh}{dx}\right)_{x=x_w} = \beta(z_w - h_w),
\]

(5)

which assumes there is continuity of groundwater heads at \(x_w\).

**Non-Dimensional Equations**

The following non-dimensional parameters with values between 0 and 1 are defined:

\[h^* = \frac{h}{h_f}, \quad x^* = \frac{x}{L}, \quad z^* = 1 - \frac{z_{ext}}{h_f}, \quad \gamma = \frac{\beta h_f}{Kb}, \quad x_w^* = \frac{x_w}{L}, \quad z_w^* = \frac{z_w}{h_f}, \quad h_w^* = \frac{h_w}{h_f}.
\]

Therefore, in non-dimensional form Equations (1a and 1b) can be rewritten as:

\[
\frac{d^2h^*}{dx^2} = \frac{aL^2}{Kbz_{ext}} \left(\frac{z_{ext}}{h_f} - 1 + h^*\right) = \left(h^* - z^*\right) \quad \text{when} \quad h^* > z^*, \text{ where } W^* = \frac{Kbh_f}{aL^2}(1 - z^*), \text{ or }
\]

(6a) \[
\frac{d^2h^*}{dx^2} = 0 \quad \text{when} \quad h^* \leq z^*.
\]

(6b)

At the river the boundary condition is:

\[h^* = 0 \quad \text{at} \quad x^* = 1.
\]

(7)

At the cliff face the boundary condition is:

\[
\frac{dh^*}{dx^*} = -q_{in} \quad \text{at} \quad x^* = 0 \quad \text{when} \quad h^* < 1 \quad (\text{i.e. no seepage}), \text{ or }
\]

(8) \[h^* = 1 \quad \text{at} \quad x^* = 0 \quad (\text{i.e. seepage}), \text{ where:}
\]

(9) \[q_{in} = \frac{Q_{in}L}{Kbh_f}.
\]

(10)

In non-dimensional form Equation (5) can be rewritten:
The Floodplain Risk Methodology (FRM)

\[- \left[ \frac{dh^*}{dx^*} \right]_{x^* = h_w} = \gamma \left( z_w^* - h_w^* \right). \]  \hspace{1cm} (11)

Parameters and Equations of Interest

1. The flux of groundwater to the river:
\[ Q_r = -K_b \frac{dh}{dx}, \text{ at } x = L, \text{ and} \]
\[ q_r = -\frac{dh^*}{dx^*}, \text{ at } x^* = 1. \] \hspace{1cm} (12) \hspace{1cm} (13)

2. The floodplain aquifer capacity, the maximum groundwater flux through the floodplain aquifer:
\[ Q_{\text{max}} = -K_b \frac{dh}{dx}, \text{ at } x = 0 \text{ and } h = h_f \text{ when seepage occurs}, \text{ and} \]
\[ q_{\text{max}} = -\frac{dh^*}{dx^*}, \text{ at } x^* = 0 \text{ and } h^* = 1 \text{ when seepage occurs}. \] \hspace{1cm} (14) \hspace{1cm} (15)

3. The groundwater elevation at the wetland \( h_w \text{ at } x = x_w \)

4. The solutions to Equations (6a and b) are:
\[ h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) \text{ for } h^* > z^*, \text{ or} \]
\[ h^* = C x^* + D \text{ for } h^* \leq z^*. \] \hspace{1cm} (16) \hspace{1cm} (17)

Possible Floodplain – Wetland Model Scenarios

As shown in Figure A1 there are 12 possible scenarios that can be summarised by the following table based on the level of the floodplain water table at the edge of the river valley, the wetland and at the river:

<table>
<thead>
<tr>
<th>Highland to Wetland</th>
<th>Wetland</th>
<th>Wetland to River</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt; ( x^* &lt; x_w^* )</td>
<td>( x_w^* )</td>
<td>( x_w^* &lt; x^* &lt; 1 )</td>
</tr>
</tbody>
</table>

A. Seepage
B. Within the extinction depth
C. Below the extinction depth
D. Within the extinction depth
E. Below the extinction depth
F. Within the extinction depth
G. Below the extinction depth

In the following sections we solve for each of the sub-cases between the highland and the wetland, and between the wetland and the river.

Case AD – Highland seepage, wetland groundwater within extinction depth

The area between the highland and \( x_w^* (0 < x^* < x_w^*) \)

At \( x^* = 0, h^* = 1, \) therefore from Equation (16):
\[ 1 = z^* + A. \] \hspace{1cm} (18)

The maximum groundwater flux into the floodplain aquifer, \( q_{\text{max}} \), is defined as in Equation (15) and therefore:
\[ q_{\text{max}} = -\frac{B}{\sqrt{W^*}}, \] \hspace{1cm} (19)

and so Equation (16) is recast to:
The Floodplain Risk Methodology (FRM)

\[ h^* = z^* + (1 - z^*) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right). \]  

(20)

The groundwater flux from the highland side into the wetland \( (q_w^*) \) is given by:

\[ q_w^* = -\frac{1 - z^*}{\sqrt{W^*}} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) + q_{\text{max}} \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) \]  

(21)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = z^* + (1 - z^*) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) \]  

(22)

Case AE – Highland seepage, wetland groundwater below extinction depth

The area between the highland and \( x_{\text{crit}}^H \) \((0 < x < x_{\text{crit}}^H)\)

Equation (20) also applies to this case:

\[ h^* = z^* + (1 - z^*) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right). \]  

(23)

By definition \( h^* = z^* \) at \( x = x_{\text{crit}}^H \), therefore:

\[ 0 = (1 - z^*) \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right). \]  

(24)

and rearranging Equation (24) gives:

\[ \tanh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) = \frac{1 - z^*}{q_{\text{max}} \sqrt{W^*}}. \]  

(25)

The groundwater flux at \( x_{\text{crit}}^H \) is:

\[ \frac{dh^*}{dx} = -\frac{1 - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) + q_{\text{max}} \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right), \]  

(26)

which can be rewritten as:

\[ \frac{dh^*}{dx} = -q_{\text{max}} \left[ \frac{1 - z^*}{q_{\text{max}} \sqrt{W^*}} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) - \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \right]. \]  

(27)

Substituting Equation (25) into Equation (27) gives:

\[ \frac{dh^*}{dx} = -q_{\text{max}} \left[ \sinh^2 \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) - \cosh^2 \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \right] \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right). \]  

(28)

Therefore, the groundwater flux from the highland side into the wetland is equal to:

\[ q_w^* = \frac{q_{\text{max}}}{\cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right)}. \]  

(29)

The area between \( x_{\text{crit}}^H \) and the wetland \((x_{\text{crit}}^H < x < x_w)\)

The groundwater level is below the extinction depth so:
\[ h^* = q_w^* \left( x_w^* - x^* \right) + z^*. \] (30)

Therefore, the groundwater head at the wetland, \( h_w^* \), is:
\[ h_w^* = q_w^* \left( x_w^{*H} - x_w^* \right) + z^*. \] (31)

**Case BD – Highland and wetland groundwater within extinction depth**

**The area between the highland and the wetland** \( (0 < x^* < x_w^*) \)

The groundwater flux into the floodplain is given by:
\[ q_{in} = \frac{d h^*}{dx} \text{ at } x^* = 0 \] (32)

So from Equation (16):
\[ q_{in} = -\frac{B}{\sqrt{W^*}}, \text{ and } \] (33)
\[ h_0^* = z^* + A, \text{ where:} \]
\[ h_0^* \] is the groundwater head at the highland. (34)

The groundwater flux from the wetland towards the river is given by:
\[ q_w^* = -\frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + q_{in} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \] (35)

The groundwater head at the wetland, \( h_w^* \) from the highland side is given by:
\[ h_w^* = z^* + \left( h_0^* - z^* \right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \] (36)

**Case BE – Highland groundwater within, wetland groundwater below extinction depth**

**The area between the highland and \( x_{crit}^{*H} \) \( (0 < x^* < x_{crit}^{*H}) \)**

Equations (16), (33) and (34) also apply to this case, so:
\[ h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right), \text{ and } \] (37)
\[ h_0^* = z^* + A. \] (38)

Substituting Equation (38) into Equation (37) gives:
\[ h^* = z^* + \left( h_0^* - z^* \right) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right). \] (39)

By definition \( h^* = z^* \) at \( x^* = x_{crit}^{*H} \), therefore:
\[ 0 = \left( h_0^* - z^* \right) \cosh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right), \] (40)

and rearranging Equation (40) gives:
\[ \tanh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right) = \frac{\left( h_0^* - z^* \right)}{q_{in} \sqrt{W^*}} \] (41)

The groundwater flux at \( x_{crit}^{*H} \) is:
\[ -\frac{dh^*}{dx} = -\frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right) + q_{in} \cosh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right) \] (42)
This is equal to the groundwater flux from the highland side into the wetland:

\[ q^*_w = \frac{q_{in}}{\cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right)} \]  

(43)

**The area between \( x^*_w \) and the wetland \( x^*_w < x^* < x_w^* \)**

The area between \( x^*_w \) and the wetland \( x^*_w < x^* < x_w^* \)

The groundwater level is below the extinction depth so:

\[ h^* = q^*_w (x^*_w - x^*) + z^* \]  

(44)

Therefore, the groundwater head at the wetland, \( h_w^* \), is:

\[ h_w^* = q^*_w (x^*_w - x_w^*) + z^* \]  

(45)

**Case CD – Highland groundwater below, wetland groundwater within extinction depth**

The area between the highland and \( x^*_w \) \( (0 < x^* < x^*_w) \)

The groundwater level is below the extinction depth so:

\[ h^* = h^* - A x^* \]  

(46)

From Equation (8) and differentiating Equation (46):

\[ q_{in} = -\frac{dh^*}{dx^*} = A \]  

(47)

Substituting \( q_{in} \) into Equation (46) gives:

\[ h^* = h^* - q_{in} x^* \]  

(48)

By definition \( h^* = z^* \) at \( x^* = x^*_w \), therefore Equation (48) can be recast to:

\[ z^* = h^* - q_{in} x^*_w \]  

(49)

and rearranged to give:

\[ h^*_0 = z^* + q_{in} x^*_w \]  

(50)

**The area between \( x^*_w \) and the wetland \( x^*_w < x^* < x_w^* \)**

Equation (16) applies to this case:

\[ h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) \]  

(51)

and by definition \( h^* = z^* \) at \( x^* = x^*_w \), therefore:

\[ 0 = z^* + A \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \]  

(52)

Now:

\[ \tanh \left( \frac{x^*_w}{\sqrt{W^*}} \right) = -\frac{A}{B} \]  

(53)

and noting that as there is no evapotranspiration in this area, \( q_{in} \) is equal to the groundwater gradient at \( x^*_w \) and therefore:

\[ q_{in} = -\frac{A}{\sqrt{W^*}} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - \frac{B}{\sqrt{W^*}} \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \]  

(54)

Substituting B from Equation (53) into this equation gives:
\[ q_{\text{in}} = -\frac{A}{\sqrt{W^*}} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right), \]  
\text{(55)}

and so:
\[ A = -q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right), \]  
\text{(56)}
\[ B = -q_{\text{in}} \sqrt{W^*} \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right). \]  
\text{(57)}

Therefore, the groundwater head at the wetland is:
\[ h_w^* = z^* + q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \]  
\text{(58)}

which simplifies to:
\[ h_w^* = z^* - q_{\text{in}} \sqrt{W^*} \sinh \left( x_w^* - x_{\text{crit}}^H \right). \]  
\text{(59)}

The groundwater flux from the floodplain on the cliff face side into the wetland is:
\[ q_w^- = q_{\text{in}} \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \cosh \left( \frac{x_{\text{crit}}^H}{\sqrt{W^*}} \right) \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \]  
\text{(60)}

which simplifies to:
\[ q_w^- = q_{\text{in}} \cosh \left( x_w^* - x_{\text{crit}}^H \right). \]  
\text{(61)}

**Case CE – Highland groundwater and wetland groundwater below extinction depth**

The groundwater level is below the extinction depth so:
\[ \frac{dh^*}{dx^*} = -q_{\text{in}}. \]  
\text{(62)}

Integrate Equation (62) to get:
\[ h^* = C - q_{\text{in}} x^*, \text{ at } x^* = 0 \text{ and } h^*_0 = h_0, \]  
\text{(63)}
\[ h^*_0 = h_0 - q_{\text{in}} x^*. \]  
\text{(64)}

Therefore, the groundwater head at the wetland is:
\[ h_w^* = h_0^* - q_{\text{in}} x_w^*, \]  
\text{(65)}

and the groundwater flux from the highland side of the floodplain into the wetland is:
\[ q_w^- = q_{\text{in}}. \]  
\text{(66)}

**Case DF – Wetland groundwater and river levels within extinction depth**

Equation (16) applies to this case:
\[ h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*}{\sqrt{W^*}} \right). \]  
\text{(67)}

By definition \( h^* = 0 \) at \( x^* = 1 \), therefore:
\[ 0 = z^* + A \cosh \left( \frac{1}{\sqrt{W^*}} \right) + B \sinh \left( \frac{1}{\sqrt{W^*}} \right). \]  
\text{(68)}

From the definition of \( q_i \) in Equation (13) we get:
\[ q_r = -A \sinh \left( \frac{1}{\sqrt{W^*}} \right) - B \cosh \left( \frac{1}{\sqrt{W^*}} \right), \]  
\tag{69}

and solving for A and B gives:
\[ A = -z^* \cosh \left( \frac{1}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1}{\sqrt{W^*}} \right), \]  
\tag{70}

\[ B = \frac{-A \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*}}{\cosh \left( \frac{1}{\sqrt{W^*}} \right)}. \]  
\tag{71}

Equation (71) simplifies to:
\[ B = z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right): \]  
\tag{72}

Recasting Equation (16) for \( h_w^* \) gives:
\[ h_w^* = z^* + A \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \]  
\tag{73}

and substituting for A and B and simplifying, gives the groundwater head at the wetland:
\[ h_w^* = z^* \left[ 1 - \cosh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) \right] + q_r \sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right). \]  
\tag{74}

Now the groundwater flux continuity at \( x^* = x_w^* \) leads to the following for the groundwater flux towards the river at the wetland:
\[ q_w^* = -z^* \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) + q_r \cosh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right). \]  
\tag{75}

**Case DG – Wetland groundwater within, river level below extinction depth**

**The area between \( x_w^* \text{ and the river } (x_w^* < x^* < 1) \)**

The groundwater level is below the extinction depth so:
\[ h^* = q_r \left( 1 - x^* \right), \]  
\tag{76}

and \( x_w^* \) is given by:
\[ z^* = q_r \left( 1 - x_w^* \right). \]  
\tag{77}

Hence:
\[ x_w^* = 1 - \frac{z^*}{q_r}. \]  
\tag{78}

**The area between the wetland and \( x_w^* \text{ (} x_w^* < x^* < x_w^* \text{) }**

Equation (16) applies to this case:
\[ h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*}{\sqrt{W^*}} \right), \]  
\tag{79}

and \( h^* = z^* \) at \( x_w^* \) so:
The groundwater flux at $x^*_\text{crit}$ is:

$$-\frac{dh^*}{dx^*} = -A \sinh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) - B \cosh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right).$$  \hspace{1cm} (81)

Now:

$$A = -B \tanh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right),$$ \hspace{1cm} (82)

so the groundwater flux at $x^*_\text{crit}$ is:

$$= \frac{B}{\sqrt{W^*}} \left[ \sinh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) - \cosh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) \right] = -\frac{B}{\sqrt{W^*} \cosh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right)} = q_r,$$ \hspace{1cm} (83)

and therefore:

$$B = q_r \sqrt{W^*} \cosh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) \text{ and } A = q_r \sqrt{W^*} \sinh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right).$$ \hspace{1cm} (84)

So substituting these into Equation (79) we get:

$$h^* = z^* + q_r \sqrt{W^*} \left[ \sinh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) \cosh\left(\frac{x^*}{\sqrt{W^*}}\right) - \sinh\left(\frac{x^*}{\sqrt{W^*}}\right) \cosh\left(\frac{x^*_\text{crit}}{\sqrt{W^*}}\right) \right],$$ \hspace{1cm} (85)

which simplifies to:

$$h^* = z^* + q_r \sqrt{W^*} \sinh\left(\frac{x^*_\text{crit} - x^*}{\sqrt{W^*}}\right).$$ \hspace{1cm} (86)

Differentiating Equation (86) with respect to $x^*$ gives:

$$\frac{dh^*}{dx^*} = q_r \cosh\left(\frac{x^*_\text{crit} - x^*}{\sqrt{W^*}}\right),$$ \hspace{1cm} (87)

and the groundwater flux from the wetland towards the river at $x_w^*$ is:

$$q_{w^*} = q_r \cosh\left(\frac{x^*_\text{crit} - x^*}{\sqrt{W^*}}\right).$$ \hspace{1cm} (88)

From equation (86) the groundwater level at the wetland is therefore:

$$h_w^* = z^* + q_r \sqrt{W^*} \sinh\left(\frac{x^*_\text{crit} - x^*}{\sqrt{W^*}}\right).$$ \hspace{1cm} (89)

Case EF – Wetland groundwater below, river level within extinction depth

The area between $x^*_\text{crit}$ and the river ($x^*_\text{crit} < x^* < 1$)

Equation (16) applies to this case:

$$h^* = z^* + A \cosh\left(\frac{x^*}{\sqrt{W^*}}\right) + B \sinh\left(\frac{x^*}{\sqrt{W^*}}\right),$$ \hspace{1cm} (90)

and at the river $h^* = 0$ and $x^* = 1$ and so:
\[0 = z^* + A \cosh\left(\frac{1}{\sqrt{W^*}}\right) + B \sinh\left(\frac{1}{\sqrt{W^*}}\right). \quad (91)\]

From the definition of \(q_r\) in Equation (13) we get:

\[q_r = -\frac{A}{\sqrt{W^*}} \sinh\left(\frac{1}{\sqrt{W^*}}\right) - B \cosh\left(\frac{1}{\sqrt{W^*}}\right), \quad (92)\]

and then solving for \(A\) and \(B\) gives:

\[A = q_r \sqrt{W^*} \sinh\left(\frac{1}{\sqrt{W^*}}\right) - z^* \cosh\left(\frac{1}{\sqrt{W^*}}\right), \quad (93)\]
\[B = z^* \sinh\left(\frac{1}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \cosh\left(\frac{1}{\sqrt{W^*}}\right). \quad (94)\]

Substituting the solutions for \(A\) and \(B\) into Equation (16) gives:

\[h^* = z^* - z^* \cosh\left(\frac{1-x^*}{W^*}\right) + q_r \sqrt{W^*} \sinh\left(\frac{1-x^*}{W^*}\right). \quad (95)\]

The area between the wetland and \(x^{*R}_{\text{crit}}\) \((W_w < x < x^{*R}_{\text{crit}})\)

At \(x^* = x^{*R}_{\text{crit}}\), \(h^* = z^*\) therefore:

\[0 = A \cosh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right) + B \sinh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right), \quad (96)\]

and so:

\[A = -B \tanh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right). \quad (97)\]

The groundwater flux at \(x^{*R}_{\text{crit}}\) is equal to the flux from the wetland towards the river:

\[-\frac{dh^*}{dx} \bigg|_{x=x^{*R}_{\text{crit}}} = -\frac{A}{\sqrt{W^*}} \sinh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right) - \frac{B}{\sqrt{W^*}} \cosh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right) = q^*_w \quad (98)\]

Substituting Equation (97) into Equation (98) gives:

\[q^*_w = \frac{-B}{\sqrt{W^*} \cosh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right)} \left[ \sinh^2\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right) - \cosh^2\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right) \right], \quad (99)\]

which simplifies to:

\[q^*_w = \frac{B}{\sqrt{W^*} \cosh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right)}. \quad (100)\]

Substituting \(B\) from Equation (94) into Equation (100) gives:

\[q^*_w = \frac{z^* \sinh\left(\frac{1}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \cosh\left(\frac{1}{\sqrt{W^*}}\right)}{\sqrt{W^*} \cosh\left(\frac{x^{*R}_{\text{crit}}}{\sqrt{W^*}}\right)}. \quad (101)\]

The groundwater head at the wetland \((x_w^*)\) from the river side is equal to:

\[h^*_w = z^* + q^*_w \left(\frac{x^*_w - x^{*R}_{\text{crit}}}{W_r}\right). \quad (102)\]
Substituting Equation (101) into Equation (102) gives:

\[
h_w^* = z^* + \left[ z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \right] \left( x_w^* - x_{crit}^* \right).
\]

The equation to describe the groundwater head between the wetland and \( x_{crit}^* \) is:

\[
h^* = z^* + \left[ z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \right] \left( x^* - x_{crit}^* \right).
\]

**Case EG – Wetland groundwater and river level below extinction depth**

From Equations (6b) and (13) the flux to river is:

\[
\frac{dh^*}{dx^*} = A = -q_r.
\]

Integrate Equation (105) to get:

\[
h^* = B - q_r x^*.
\]

At the river \( x^* = 1 \) and \( h^* = 0 \), so \( B = q_r \) and Equation (106) can be recast to:

\[
h^* = q_r \left( 1 - x^* \right).
\]

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[
h_w^* = q_r \left( 1 - x_w^* \right).
\]

The groundwater flux from the wetland towards the river is given by:

\[
q_w^* = q_r.
\]

**Special Cases**

In this section we describe special cases where the groundwater head at the wetland is equal to the extinction depth.

**Special Case A (z^*>0) - Highland groundwater level above, wetland groundwater level equal to and river level below the extinction depth**

The area between the highland and the wetland \((0 < x^* \leq x_w^*)\)

Equation (16) applies to this case:

\[
h^* = z^* + A \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x^*}{\sqrt{W^*}} \right),
\]

and therefore at the wetland where \( h^* = z^* \):

\[
A \cosh \left( \frac{x_{w}^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x_{w}^*}{\sqrt{W^*}} \right) = 0,
\]

and so:

\[
A = -B \tanh \left( \frac{x_{w}^*}{\sqrt{W^*}} \right).
\]

The groundwater flux from the highland towards the wetland is equal to:
\[ q_w^- = -\frac{A}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - \frac{B}{\sqrt{W^*}} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \]  

(113)

**The area between the wetland and the river \((x_w^* < x^* \leq 1)\)**

The groundwater level is below the extinction depth so:

\[ h^* = q_r \left( 1 - x_r^* \right) \]  

(114)

The groundwater flux from the wetland towards the river is equal to:

\[ q_w^* = q_r \]  

(115)

Therefore, at the wetland from the river side:

\[ z^* = q_r \left( 1 - x_r^* \right) \]  

(116)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma \left( z_w^* - h_w^* \right) = q_w^* - q_w^- \), therefore:

\[ \gamma \left( z_w^* - z_r^* \right) = q_r + \frac{A}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + \frac{B}{\sqrt{W^*}} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \]  

(117)

Substituting \( A \) from Equation (112) gives:

\[ \gamma \left( z_w^* - z_r^* \right) = q_r + \frac{B}{\sqrt{W^*}} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \left[ - \sinh^2 \left( \frac{x_w^*}{\sqrt{W^*}} \right) + \cosh^2 \left( \frac{x_w^*}{\sqrt{W^*}} \right) \right], \]  

(118)

which simplifies to:

\[ \gamma \left( z_w^* - z_r^* \right) = q_r + \frac{B}{\sqrt{W^*}} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(119)

Rearranging Equation (119) for \( B \) gives:

\[ B = \left[ \gamma \left( z_w^* - z_r^* \right) - q_r \right] \sqrt{W^*} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \]  

(120)

and so from Equation (112):

\[ A = - \left[ \gamma \left( z_w^* - z_r^* \right) - q_r \right] \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(121)

Therefore, the groundwater head at the highland is equal to:

\[ h_{0\text{special}} = z^* - \gamma \left( z_w^* - z_r^* \right) - q_r \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(122)

The groundwater flux into the floodplain to meet these conditions is given by:

\[ q_{in\text{special}} = \frac{-B}{\sqrt{W^*}} = \left[ q_r - \gamma \left( z_w^* - z_r^* \right) \right] \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \]  

(123)

Substituting \( q_r \) from Equation (116) gives:

\[ q_{in\text{special}} = \left[ \frac{z^*}{1 - x_w^*} - \gamma \left( z_w^* - z_r^* \right) \right] \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \]  

(124)

and

\[ h_{0\text{special}} = z^* - \gamma \left( z_w^* - z_r^* \right) - \frac{z^*}{1 - x_w^*} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(125)
Special Case B ($z^*<0$) - Highland groundwater level below, wetland groundwater level equal to and river level above the extinction depth

The area between the highland and the wetland ($0 < x^* \leq x_w^*$)

From Equations (6b) and (8):
\[ h^* = h_0^* - A x^* \quad \text{and} \quad q_{in} = \frac{dh^*}{dx^*} = A, \]  
(126)
and so:
\[ h^* = h_0^* - q_{in} x^*. \]  
(127)

At the wetland, $h^* = z^*$ at $x^* = x_w^*$, therefore:
\[ z^* = h_0^* - q_{in} x_w^*. \]  
(128)
So the groundwater head at the edge of the highland, $h_0^*$, is equal to:
\[ h_0^* = z^* + q_{in} x_w^*. \]  
(129)
The groundwater flux from the highland side into the wetland is given by
\[ q_{w}^* = q_{in}. \]  
(130)

The area between the wetland and the river ($x_w^* < x^* \leq 1$)

At the river, where $h^* = 0$ and $x^* = 1$, Equation (16) becomes:
\[ 0 = z^* + A \cosh\left(\frac{1}{\sqrt{W^*}}\right) + B \sinh\left(\frac{1}{\sqrt{W^*}}\right) \]  
(131)
From the definition of $q_r$ in Equation (13):
\[ q_r = -\frac{A}{\sqrt{W^*}} \sinh\left(\frac{1}{\sqrt{W^*}}\right) - \frac{B}{\sqrt{W^*}} \cosh\left(\frac{1}{\sqrt{W^*}}\right) \]  
(132)
Solving Equations (131) and (132) for A and B gives:
\[ A = q_r \sqrt{W^*} \sinh\left(\frac{1}{\sqrt{W^*}}\right) - z^* \cosh\left(\frac{1}{\sqrt{W^*}}\right), \]  
(133)
\[ B = -q_r \sqrt{W^*} \cosh\left(\frac{1}{\sqrt{W^*}}\right) + z^* \sinh\left(\frac{1}{\sqrt{W^*}}\right). \]  
(134)
Substituting the solutions for A and B into Equation (16) gives:
\[ h^* = z^* - z^* \cosh\left(\frac{1-x^*}{\sqrt{W^*}}\right) + q_r \sqrt{W^*} \sinh\left(\frac{1-x^*}{\sqrt{W^*}}\right). \]  
(135)
At the wetland, where $h^* = z^*$ and $x^* = x_w^*$, Equation (16) becomes:
\[ 0 = A \cosh\left(\frac{x_w^*}{\sqrt{W^*}}\right) + B \sinh\left(\frac{x_w^*}{\sqrt{W^*}}\right), \]  
(136)
and so:
\[ \frac{-A}{B} = \frac{\sinh\left(\frac{x_w^*}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \sinh\left(\frac{1}{\sqrt{W^*}}\right) + z^* \cosh\left(\frac{1}{\sqrt{W^*}}\right)}{\cosh\left(\frac{x_w^*}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \cosh\left(\frac{1}{\sqrt{W^*}}\right) + z^* \sinh\left(\frac{1}{\sqrt{W^*}}\right)}. \]  
(137)
and therefore:

\[ q_r = \frac{z^*}{\sqrt{W^*} \tanh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)} \tag{138} \]

The groundwater flux from the wetland towards the river is equal to:

\[ q_w^* = -\frac{A}{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - \frac{B}{W^*} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \tag{139} \]

Substituting the solutions for A and B in Equations (133) and (134) into Equation (139) gives:

\[ q_w^* = q_r \cosh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) - z^* \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) \tag{140} \]

Substituting Equation (138) for \( q_r \) into Equation (140) gives:

\[ q_w^* = \frac{z^*}{\sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)} \tag{141} \]

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e.

\[ \gamma \left( z_w^* - h_{w}^* \right) = q_w^* - q_{w}^* \], therefore:

\[ \gamma \left( z_w^* - z^* \right) = \frac{z^*}{\sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)} - q_{w}^* \tag{142} \]

Rearranging Equation (142) gives:

\[ q_{\text{in special } \beta} = \frac{z^*}{\sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)} - \gamma \left( z_w^* - z^* \right) \], and

\[ h_{0 \text{ special } \beta} = z^* + \frac{z^*}{\sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)} - \gamma \left( z_w^* - z^* \right) x_w^* \tag{144} \]

### Special Case C (\( z^* < 0 \)) - Highland groundwater level above, wetland groundwater level equal to and river level above the extinction depth

The area between the highland and the wetland (\( 0 < x^*_w < x_w^* \))

Equations (16), (33) and (34) apply to this case, so:

\[ h^* = z^* + A \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right), \] and

\[ h_{0}^* = z^* + A \tag{145} \]

Therefore:

\[ h^* = z^* + (h_{0}^* - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \tag{147} \]

At the wetland, \( h_w^* = z^* \), therefore:
0 = \left( h_0^* - z^* \right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \quad (148)

and so:
\[
\tanh \left( \frac{x_w^*}{\sqrt{W^*}} \right) = \frac{\left( h_0^* - z^* \right)}{q_{in} \sqrt{W^*}}. \quad (149)
\]

The groundwater flux from the highland side into the wetland is given by:
\[
q_w^* = -\frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + q_{in} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \quad (150)
\]

and this is equal to the floodplain groundwater flux from the highland side into the wetland:
\[
q_w^* = \frac{q_{in}}{\cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right)}. \quad (151)
\]

**The area between the wetland and the river \(x_w^*<x^* \leq 1\)**

At the river when \(h^*=0\) and \(x^*=1\) and so Equation (16) becomes:
\[
0 = z^* + A \cosh \left( \frac{1}{\sqrt{W^*}} \right) + B \sinh \left( \frac{1}{\sqrt{W^*}} \right). \quad (152)
\]

From the definition of \(q_r\) in Equation (13):
\[
q_r = -\frac{A}{\sqrt{W^*}} \sinh \left( \frac{1}{\sqrt{W^*}} \right) - \frac{B}{\sqrt{W^*}} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \quad (153)
\]

Solving Equations (152) and (153) for \(A\) and \(B\) gives:
\[
A = q_r \sqrt{W^*} \sinh \left( \frac{1}{\sqrt{W^*}} \right) - z^* \cosh \left( \frac{1}{\sqrt{W^*}} \right), \quad (154)
\]
\[
B = -q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) + z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right). \quad (155)
\]

Substituting the solutions for \(A\) and \(B\) into Equation (16) gives:
\[
h^* = z^* - z^* \cosh \left( \frac{1-x^*}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1-x^*}{\sqrt{W^*}} \right) \quad (156)
\]

At the wetland, where \(h^*=z^*\) and \(x^*=x_w^*\), Equation (16) becomes:
\[
0 = A \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + B \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right), \quad (157)
\]

and so:
\[
-\frac{A}{B} = \frac{\sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right)}{\cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right)} = -q_r \sqrt{W^*} \sinh \left( \frac{1}{\sqrt{W^*}} \right) + z^* \cosh \left( \frac{1}{\sqrt{W^*}} \right) \quad (158)
\]

and therefore:
\[
q_r = \frac{z^*}{\sqrt{W^*} \tanh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)}. \quad (159)
\]
The groundwater flux from the wetland towards the river is equal to:

\[ q_w^* = -\frac{A}{\sqrt{W'}} \sinh\left(\frac{x_w^*}{\sqrt{W'}}\right) - \frac{B}{\sqrt{W'}} \cosh\left(\frac{x_w^*}{\sqrt{W'}}\right) \]  

(160)

Substituting the solutions for A and B in Equations (154) and (155) into Equation (160) gives:

\[ q_w^* = q_r \cosh\left(\frac{1-x_w^*}{\sqrt{W'}}\right) - \frac{z^*}{\sqrt{W'}} \sinh\left(\frac{1-x_w^*}{\sqrt{W'}}\right) \]  

(161)

Substituting Equation (159) for \( q_r \) into Equation (161) gives:

\[ q_w^* = \frac{z^*}{\sqrt{W'} \sinh\left(\frac{1-x_w^*}{\sqrt{W'}}\right)} \]  

(162)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma (z_w^* - h_w^*) = q_w^* - q_w^* \), therefore:

\[ \gamma (z_w^* - h_w^*) = \frac{z^*}{\sqrt{W'} \sinh\left(\frac{1-x_w^*}{\sqrt{W'}}\right)} - \frac{q_w}{\cosh\left(\frac{x_w^*}{\sqrt{W'}}\right)} \]  

(163)

Rearranging Equation (163) gives:

\[ q_{in \ special \ x} = \cosh\left(\frac{x_w^*}{\sqrt{W'}}\right) \frac{z^*}{\sqrt{W'} \sinh\left(\frac{1-x_w^*}{\sqrt{W'}}\right)} - \gamma \left(z_w^* - z^*\right) \]  

(164)

\[ h_{0 \ special \ x} = z^* + \sqrt{W'} \sinh\left(\frac{x_w^*}{\sqrt{W'}}\right) \frac{z^*}{\sqrt{W'} \sinh\left(\frac{1-x_w^*}{\sqrt{W'}}\right)} - \gamma \left(z_w^* - z^*\right) \]  

(165)

### Matching the Boundary Conditions at the Wetland

In this section we use the continuity of groundwater head at the wetland, and leakage from the wetland, to combine the fluxes from the highland and river sides of the wetland. This provides the solutions for each of the 12 scenarios.

**Case ADF - Highland and wetland groundwater levels and river levels above the extinction depth with seepage.**

The groundwater flux from the highland side into the wetland is given by:

\[ q_w^* = -\frac{1-z^*}{\sqrt{W'}} \sinh\left(\frac{x_w^*}{\sqrt{W'}}\right) + q_{max} \cosh\left(\frac{x_w^*}{\sqrt{W'}}\right) \]  

(166)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = z^* + (1-z^*) \cosh\left(\frac{x_w^*}{\sqrt{W'}}\right) - q_{max} \sqrt{W'} \sinh\left(\frac{x_w^*}{\sqrt{W'}}\right) \]  

(167)

which can be rearranged to give an equation for \( q_{max} \):
The Floodplain Risk Methodology (FRM)

\[ z^* - h^*_w + (1 - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \]

\[ q_{\text{max}} = \frac{1}{\sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right)} \cdot \]  

(168)

The groundwater flux from the wetland towards the river is given by:

\[ q_w^* = -\frac{z^*}{\sqrt{W^*}} \sinh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) + q_r \cosh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(169)

The groundwater head at the wetland, \(h_w^*\), from the river side is equal to:

\[ h_w^* = z^* \left( 1 - \cosh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) \right) + q_r \sqrt{W^*} \sinh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(170)

Equating the groundwater heads at the wetland gives:

\[ z^* \left[ 1 - \cosh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) \right] + q_r \sqrt{W^*} \sinh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) = z^* + (1 - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(171)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, \(\gamma (z^*_w - h^*_w) = q_w^* - q_{\text{max}}^*\), therefore:

\[ \gamma (z^*_w - h^*_w) = -\frac{z^*}{\sqrt{W^*}} \sinh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) + q_r \cosh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) + \frac{1 - z^*}{\sqrt{W^*}} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{max}} \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(172)

The groundwater level between the highland and the wetland can be calculated from:

\[ h^* = z^* + (1 - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \text{ when } 0 < x^* \leq x^*_w \cdot \]  

(173)

The groundwater level between the wetland and the river can be calculated from:

\[ h^* = z^* - z^* \cosh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1 - x^*_w}{\sqrt{W^*}} \right) \text{ when } x^*_w < x^* \leq 1 \cdot \]  

(174)

**Case ADG - Highland and wetland groundwater levels above, river level below the extinction depth with seepage**

The groundwater flux from the highland side into the wetland is given by:

\[ q_w^* = -\frac{1 - z^*}{\sqrt{W^*}} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) + q_{\text{max}} \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(175)

The groundwater head at the wetland, \(h_w^*\), from the highland side is equal to:

\[ h_w^* = z^* + (1 - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \cdot \]  

(176)

which can be rearranged to give an equation for \(q_{\text{max}}\)

\[ z^* - h_w^* + (1 - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \]

\[ q_{\text{max}} = \frac{1}{\sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right)} \cdot \]  

(177)
The groundwater flux from the wetland towards the river is given by:

\[ q_w^* = q_r \cosh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right), \]

where \( x_{crit}^* = 1 - \frac{z^*}{q_r} \).

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right). \]

Equating the groundwater heads at the wetland gives:

\[ z^* + q_r \sqrt{W^*} \sinh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right) = z^* + \left(1 - z^*\right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{max} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma \left(z_w^* - h_w^*\right) = q_{w}^* - q_w^* \), therefore:

\[ \gamma \left(z_w^* - h_w^*\right) = q_r \cosh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right) + \left(1 - z^*\right) \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{max} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]

The groundwater level between the highland and the wetland can be calculated from:

\[ h^* = z^* + \left(1 - z^*\right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{max} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \text{ when } 0 < x_w^* \leq x_{crit}^*. \]

The groundwater level between the wetland and \( x_{crit}^* \) can be calculated from:

\[ h^* = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x_{crit}^* - x^*}{\sqrt{W^*}} \right) \text{ when } x_w^* < x^* \leq x_{crit}^*. \]

The groundwater level between \( x_{crit}^* \) and the river can be calculated from:

\[ h^* = q_r \left(1 - x^*\right) \text{ when } x_{crit}^* < x^* \leq 1. \]

**Case AEF** - Highland groundwater level above, wetland groundwater level below and river level above the extinction depth with seepage

The maximum groundwater flux into the floodplain is given by:

\[ q_{max} = \frac{1 - z^*}{\sqrt{W^*} \tanh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right)}. \]

The groundwater flux from the highland side into the wetland is given by:

\[ q_w^* = \frac{q_{max}}{\cosh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right)} \quad \text{or} \quad q_w^* = \frac{1 - z^*}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right)}. \]

The equation for \( x_{crit}^{*H} \) is given by:

\[ \tanh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right) = \frac{1 - z^*}{q_{max} \sqrt{W^*}}. \]

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = \frac{1 - z^*}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^{*H}}{\sqrt{W^*}} \right)} \left(x_{crit}^{*H} - x_w^*\right) + z^*. \]
The groundwater flux from the wetland towards the river is given by:

\[ q_w^* = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)}. \]  

(189)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* + \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)} \left( x_w^* - x_{crit}^R \right). \]  

(190)

Equating the groundwater heads at the wetland gives:

\[ \frac{1 - z^*}{\sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)} (x_{crit}^H - x_w^*) = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)} \left( x_w^* - x_{crit}^R \right). \]  

(191)

The equation for \( x_{crit}^R \) is given by:

\[ \tanh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right) = \frac{-q_r \sqrt{W^*} \sinh \left( \frac{1}{\sqrt{W^*}} \right) + z^* \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}, \]  

(192)

which can be rearranged to give an equation for \( q_r \):

\[ q_r = \frac{z^* \sqrt{W^*} \tanh \left( \frac{1 - x_{crit}^R}{\sqrt{W^*}} \right)}{z^* - \sqrt{W^*} \tanh \left( \frac{1 - x_{crit}^R}{\sqrt{W^*}} \right)}. \]  

(193)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma (z_w^* - h_w^*) = q_w^* - q_r^* \), therefore:

\[ \gamma (z_w^* - h_w^*) = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)} - \frac{1 - z^*}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)}, \]  

(194)

which can be rearranged to give an equation to solve for \( x_{crit}^H \) using the arc sinh function:

\[ \sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right) = \frac{(1 - z^*) \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)}{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) - \gamma \sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right) (z_w^* - h_w^*)}. \]  

(195)

The groundwater level between the highland and \( x_{crit}^H \) can be calculated from:

\[ h^* = z^* + (1 - z^*) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{max} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) \text{ when } 0 < x^* \leq x_{crit}^H. \]  

(196)
The groundwater level between \( x_{crit}^H \) and the wetland can be calculated from:

\[
h^* = \frac{q_{max} (x_{crit}^H - x^*)}{\cosh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)} + z^* \quad \text{when } x_{crit}^H < x^* \leq x_w^*.
\]  \( (197) \)

The groundwater level between the wetland and \( x_{crit}^R \) can be calculated from:

\[
h^* = z^* + \frac{q_r \sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)}{\cosh \left( \frac{x^* - x_{crit}^R}{\sqrt{W^*}} \right)} \quad \text{when } x_w^* < x^* \leq x_{crit}^R.
\]  \( (198) \)

The groundwater level between \( x_{crit}^R \) and the river can be calculated from:

\[
h^* = z^* - z^* \cosh \left( \frac{1-x^*}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1-x^*}{\sqrt{W^*}} \right) \quad \text{when } x_{crit}^R < x^* \leq 1.
\]  \( (199) \)

**Case AEG - Highland groundwater level above, wetland groundwater and river levels below the extinction depth with seepage**

The maximum groundwater flux into the floodplain is given by:

\[
q_{max} = \frac{1 - z^*}{\sqrt{W^*} \tanh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)}.
\]  \( (200) \)

The groundwater flux from the highland side into the wetland is given by:

\[
q_w^* = \frac{q_{max}}{\cosh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)} = \frac{1 - z^*}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)}.
\]  \( (201) \)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[
h_w^* = \frac{1 - z^*}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)} \left( x_{crit}^H - x_w^* \right) + z^*.
\]  \( (202) \)

The groundwater flux from the wetland towards the river is given by:

\[
q_w^* = q_r.
\]  \( (203) \)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[
h_w^* = q_r (1 - x_w^*).
\]  \( (204) \)

Equating the groundwater heads at the wetland gives:

\[
q_r (1 - x_w^*) = \frac{(1 - z^*) \left( x_{crit}^H - x_w^* \right)}{\sqrt{W^*} \sinh \left( \frac{x_{crit}^H}{\sqrt{W^*}} \right)} + z^*.
\]  \( (205) \)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma (z_w^* - h_w^*) = q_w^* - q_w^* \), therefore:
\[ \gamma(z_w^* - h_w^*) = q_r - \frac{1 - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_{\text{crit}}^*}{\sqrt{W^*}} \right). \]  

(206)

This means \( x_{\text{crit}}^* \) can be solved by substituting values of \( q_r \) into

\[ x_{\text{crit}}^* = \frac{h_w^* - z^*}{q_r - \gamma(z_w^* - h_w^*)} + x_w^*. \]  

(207)

The groundwater level between the highland and \( x_{\text{crit}}^* \) can be calculated from:

\[ h^* = z^* + (1 - z^*) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{\text{max}} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \quad \text{when} \quad 0 < x^* \leq x_{\text{crit}}^*. \]  

(208)

The groundwater level between \( x_{\text{crit}}^* \) and the wetland can be calculated from:

\[ h^* = \frac{q_{\text{max}} (x_w^* - x^*)}{\cosh \left( \frac{x_{\text{crit}}^*}{\sqrt{W^*}} \right)} + h_w^* \quad \text{when} \quad x_{\text{crit}}^* < x^* \leq x_w^*. \]  

(209)

The groundwater level between the wetland and the river can be calculated from:

\[ h^* = q_r (1 - x^*) \quad \text{when} \quad x_w^* < x^* \leq 1. \]  

(210)

**Case BDF - Highland and wetland groundwater and river levels above the extinction depth**

The groundwater flux from the highland side into the wetland is given by:

\[ q_w^* = -\frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + q_{\text{in}} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(211)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = z^* + (h_0^* - z^*) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  

(212)

The groundwater flux from the wetland towards the river is given by:

\[ q_w^* = -\frac{z^*}{\sqrt{W^*}} \sinh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) + q_r \cosh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right). \]  

(213)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* \left[ 1 - \cosh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) \right] + q_r \sqrt{W^*} \sinh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right). \]  

(214)

Equating the groundwater heads at the wetland gives:

\[ z^* + (h_0^* - z^*) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) = z^* \left[ 1 - \cosh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) \right] + q_r \sqrt{W^*} \sinh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) \]  

(215)

Therefore, the groundwater head at the highland, \( h_0^* \), is equal to:

\[ h_0^* = z^* + \frac{-z^* \cosh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1 - x_w^*}{\sqrt{W^*}} \right) + q_{\text{in}} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right)}{\cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right)}. \]  

(216)
Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. $\gamma \left( z_w^* - h_w^* \right) = q_w^* - q_w^*$, therefore:

$$
\gamma \left( z_w^* - z^* \right) = -\frac{z^*}{\sqrt{W^*}} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) + q_r \cosh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right) + h_0^* - z^* \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_m \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right).
$$

(217)

Substituting Equation (216) for $h_o^*$ into Equation (217) gives an equation to solve for $q_r$:

$$
q_r = \frac{\cosh \left( \frac{1}{\sqrt{W^*}} \right) + \gamma \sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)}{\cosh \left( \frac{1}{\sqrt{W^*}} \right) + \gamma \sqrt{W^*} \sinh \left( \frac{1-x_w^*}{\sqrt{W^*}} \right)}.
$$

(218)

The groundwater level between the highland and the wetland can be calculated from:

$$
h_w^* = z^* + (h_0^* - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_m \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) \quad \text{when} \quad 0 < x^*_w \leq 1.
$$

(219)

The groundwater level between the wetland and the river can be calculated from:

$$
h^*_r = z^* - z^* \cosh \left( \frac{1-x^*_r}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1-x^*_r}{\sqrt{W^*}} \right) \quad \text{when} \quad x^*_w < x^*_r \leq 1.
$$

(220)

**Case BDG - Highland and wetland groundwater levels, river level below extinction depth**

The groundwater flux from the highland side into the wetland is given by:

$$
q_{w^*} = -\frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) + q_m \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right).
$$

(221)

The groundwater head at the wetland, $h_{w^*}$, from the highland side is equal to:

$$
h_{w^*} = z^* + (h_0^* - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_m \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right).
$$

(222)

The groundwater flux from the wetland towards the river is given by:

$$
q_{w^*} = q_r \cosh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right), \quad \text{where} \quad x^*_r = 1 - \frac{z^*}{q_r}.
$$

(223)

The groundwater head at the wetland, $h_{w^*}$, from the river side is equal to:

$$
h_{w^*} = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right).
$$

(224)

Equating the groundwater heads at the wetland gives:

$$
z^* + q_r \sqrt{W^*} \sinh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right) = z^* + (h_0^* - z^*) \cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right) - q_m \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right).
$$

(225)

Therefore, the groundwater head at the highland, $h_0^*$, is equal to:

$$
h_0^* = z^* + \frac{q_m \sqrt{W^*} \sinh \left( \frac{x^*_w}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right)}{\cosh \left( \frac{x^*_w}{\sqrt{W^*}} \right)}.
$$

(226)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. $\gamma \left( z_w^* - h_w^* \right) = q_w^* - q_w^*$, therefore:
The Floodplain Risk Methodology (FRM)

\[ \gamma(z^* - h_w^*) = q_a \cosh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right) + \frac{h_0^* - z^*}{\sqrt{W^*}} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{in} \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right). \]  \hspace{1cm} (227)

The groundwater level between the highland and the wetland can be calculated from:

\[ h^* = z^* + \left( h_0^* - z^* \right) \cosh \left( \frac{x_w^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x_w^*}{\sqrt{W^*}} \right) \text{ when } 0 < x^* \leq x_{crit}^*. \]  \hspace{1cm} (228)

The groundwater level between the wetland and \( x_{crit}^* \) can be calculated from:

\[ h^* = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x_{crit}^* - x_w^*}{\sqrt{W^*}} \right) \text{ when } x_{crit}^* < x^* \leq x_{crit}^*. \]  \hspace{1cm} (229)

The groundwater level between \( x_{crit}^* \) and the river can be calculated from:

\[ h^* = q_r \left( 1 - x^* \right) \text{ when } x_{crit}^* < x^* \leq 1. \]  \hspace{1cm} (230)

**Case BEF - Highland groundwater above, wetland groundwater below and river level above the extinction depth**

The groundwater flux from the highland side into the wetland is given by:

\[ q_{w^-} = \frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)}. \]  \hspace{1cm} (231)

The equation for \( x_{crit}^* \) is given by:

\[ \tanh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right) = \frac{h_0^* - z^*}{q_{in} \sqrt{W^*}}. \]  \hspace{1cm} (232)

Therefore, the groundwater head at the highland, \( h_0^* \), is equal to:

\[ h_0^* = q_{in} \sqrt{W^*} \tanh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right) + z^*. \]  \hspace{1cm} (233)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = -\frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \left( x_{crit}^* - x_{crit}^* \right) + z^*. \]  \hspace{1cm} (234)

The groundwater flux from the wetland towards the river is given by:

\[ q_{w^+} = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \].  \hspace{1cm} (235)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* + \left[ \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \right] \left( x_{crit}^* - x_w^* \right). \]  \hspace{1cm} (236)

Equating the groundwater heads at the wetland gives:
The equation for $X_{crit}^R$ is given by:

$$
\frac{q_r}{z^*} = \frac{z^*}{W^* \tanh \left( \frac{1 - X_{crit}^R}{\sqrt{W^*}} \right)}.
$$

(239)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. $\gamma(z_w^* - h_w^*) = q_w^* - q_w^*$, therefore:

$$
\gamma(z_w^* - h_w^*) = \frac{z^*}{\sqrt{W^*}} - q_r\sqrt{W^*}cosh\left( \frac{1}{\sqrt{W^*}} \right),
$$

(240)

which can be rearranged to give an equation to solve for $X_{crit}^H$ using an arc cosh function:

$$
\cosh\left( \frac{X_{crit}^H}{\sqrt{W^*}} \right) = \frac{q_{in} \sqrt{W^*} \cosh\left( \frac{X_{crit}^R}{\sqrt{W^*}} \right) + z^* \sinh\left( \frac{1}{\sqrt{W^*}} \right) - q_r \cosh\left( \frac{X_{crit}^R}{\sqrt{W^*}} \right)}{z^* \sinh\left( \frac{1}{\sqrt{W^*}} \right) - q_r \cosh\left( \frac{1}{\sqrt{W^*}} \right)}
$$

(241)

Note that only $\text{acosh}(x)$ where $x > 1$ is possible.

The groundwater level between the highland and $X_{crit}^H$ can be calculated from:

$$
h^* = z^* + (h_0^* - z^*) \text{cosh}\left( \frac{X_{crit}^H}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh\left( \frac{X_{crit}^H}{\sqrt{W^*}} \right) \quad \text{when} \quad 0 < x^* \leq x_{crit}^H.
$$

(242)

The groundwater level between $X_{crit}^H$ and the wetland can be calculated from:

$$
h^* = \frac{q_{in} (X_{crit}^H - x^*)}{\text{cosh}\left( \frac{X_{crit}^H}{\sqrt{W^*}} \right)} + z^* \quad \text{when} \quad x_{crit}^H < x^* \leq x_w^*.
$$

(243)

The groundwater level between the wetland and $X_{crit}^H$ can be calculated from:

$$
h^* = z^* + \frac{z^* \sinh\left( \frac{1}{\sqrt{W^*}} \right) - q_r \cosh\left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh\left( \frac{X_{crit}^R}{\sqrt{W^*}} \right)} (x^* - x_{crit}^R) \quad \text{when} \quad x_w^* < x^* \leq x_{crit}^R.
$$

(244)
The Floodplain Risk Methodology (FRM)

The groundwater level between \( x_{crit}^* \) and the river can be calculated from:

\[
h^* = z^* - z^* \cosh \left( \frac{1-x^*}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1-x^*}{\sqrt{W^*}} \right) \quad \text{when} \quad x_{crit}^* < x^* \leq 1. \tag{245}
\]

Case BEG Highland groundwater above, wetland groundwater and river levels below the extinction depth

The groundwater flux from the highland side into the wetland is given by:

\[
q_w^* = \frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)}. \tag{246}
\]

Noting that the equation for \( x_{crit}^* \) is given by:

\[
\tanh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right) = \frac{h_{in}^* - z^*}{q_{in} \sqrt{W^*}}. \tag{247}
\]

Therefore, the groundwater head at the highland, \( h_0^* \), is equal to:

\[
h_0^* = q_{in} \sqrt{W^*} \tanh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right) + z^*. \tag{248}
\]

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[
h_w^* = q_w^* \left( x_{crit}^{*H} - x_w^* \right) + z^* \quad \text{or} \quad h_w^* = \frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \left( x_{crit}^{*H} - x_w^* \right) + z^*. \tag{249}
\]

The groundwater flux from the wetland towards the river is given by:

\[
q_r = q_r. \tag{250}
\]

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[
h_w^* = q_r \left( 1 - x_w^* \right). \tag{251}
\]

Equating the groundwater heads at the wetland gives:

\[
q_r \left( 1 - x_w^* \right) = \frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \left( x_{crit}^{*H} - x_w^* \right) + z^*. \tag{252}
\]

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, \emph{i.e.} \( \gamma (z_w^* - h_w^*) = q_r^* - q_w^* \), therefore:

\[
\gamma (z_w^* - h_w^*) = q_r - \frac{q_{in}}{\cosh \left( \frac{x_{crit}^*}{\sqrt{W^*}} \right)} \tag{253}
\]

This means \( x_{crit}^{*H} \) can be solved by substituting values of \( q_r \) into:

\[
x_{crit}^{*H} = \frac{h_{in}^* - z^*}{q_r - \gamma (z_w^* - h_w^*)} + x_w^*. \tag{254}
\]

The groundwater level between the highland and \( x_{crit}^{*H} \) can be calculated from:

\[
h^* = z^* + \left( h_0^* - z^* \right) \cosh \left( \frac{x^*}{\sqrt{W^*}} \right) - q_{in} \sqrt{W^*} \sinh \left( \frac{x^*}{\sqrt{W^*}} \right) \quad \text{when} \quad 0 < x^* \leq x_{crit}^{*H}. \tag{255}
\]

The groundwater level between \( x_{crit}^{*H} \) and the wetland can be calculated from:
The Floodplain Risk Methodology (FRM)

\[ h^* = \frac{q_{in}}{\cosh\left(\frac{x^{*H}_{crit} - x^*}{\sqrt{W^*}}\right)} + z^* \quad \text{when} \quad x^{*H}_{crit} < x^* \leq x^*_w. \]  

(256)

The groundwater level between the wetland and the river can be calculated from:

\[ h^* = q_r \left(1 - x^*\right) \quad \text{when} \quad x^*_w < x^* \leq 1. \]  

(257)

**Case CDF - Highland groundwater below, wetland groundwater and river levels above the extinction depth**

The groundwater head at the highland, \( h_0^* \), is equal to:

\[ h_0^* = z^* + q_{in} x^{*H}_{crit}. \]  

(258)

The groundwater flux from the highland side into the wetland is given by:

\[ q_w^- = q_{in} \cosh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right). \]  

(259)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = z^* - q_{in} \sqrt{W^*} \sinh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right). \]  

(260)

The groundwater flux from the wetland towards the river is given by:

\[ q_w^+ = -\frac{z^*}{\sqrt{W^*}} \sinh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right) + q_r \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right). \]  

(261)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* - q_{in} \sqrt{W^*} \sinh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right). \]  

(262)

Equating the groundwater heads at the wetland gives:

\[ q_{in} \sqrt{W^*} \sinh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right) = z^* \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right) - q_r \sqrt{W^*} \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right), \]  

(263)

which can be rearranged to give an equation for \( q_r \) where only \( x^{*H}_{crit} \) is unknown:

\[ q_r = \frac{z^* \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right) - q_{in} \sqrt{W^*} \sinh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right)}{\sqrt{W^*} \sinh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right)}. \]  

(264)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma (z^*_w - h_w^*) = q_w^- - q_w^+ \), therefore:

\[ \gamma (z^*_w - h_w^*) = \frac{z^*}{\sqrt{W^*}} \sinh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right) + q_r \cosh\left(\frac{1-x^*_w}{\sqrt{W^*}}\right) - q_{in} \cosh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right). \]  

(265)

The groundwater level between the highland and \( x^{*H}_{crit} \) can be calculated from:

\[ h^* = h_0^* - q_{in} x^{*H}_{crit} \quad \text{when} \quad 0 \leq x^* \leq x^{*H}_{crit}. \]  

(266)

The groundwater level between \( x^{*H}_{crit} \) and the wetland can be calculated from:

\[ h^* = z^* - q_{in} \sqrt{W^*} \sinh\left(\frac{x^*_w - x^{*H}_{crit}}{\sqrt{W^*}}\right) \quad \text{when} \quad x^{*H}_{crit} < x^* \leq x^*_w. \]  

(267)
The groundwater level between the wetland and the river can be calculated from:

\[ h^* = z^* - z^* \cosh \left( \frac{1-x^*}{\sqrt{W^*}} \right) + q_r \sqrt{W^*} \sinh \left( \frac{1-x^*}{\sqrt{W^*}} \right) \quad \text{when} \quad x^*_w < x^* \leq 1. \]  

(268)

**Case CDG - Highland groundwater below, wetland groundwater above and river level below the extinction depth**

The groundwater head at the highland, \( h_0^* \), is equal to:

\[ h_0^* = z^* + q_m x^*_h \]  

(269)

The groundwater flux from the highland side into the wetland is given by:

\[ q_{w^*} = q_m \cosh \left( \frac{x^*_h - x^*_w}{\sqrt{W^*}} \right). \]  

(270)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:

\[ h_w^* = z^* - q_m \sqrt{W^*} \sinh \left( \frac{x^*_h - x^*_w}{\sqrt{W^*}} \right). \]  

(271)

The groundwater flux from the wetland towards the river is given by:

\[ q_{w^*} = q_r \cosh \left( \frac{x^*_w - x^*_r}{\sqrt{W^*}} \right) \quad \text{where} \quad x^*_r = 1 - \frac{z^*}{q_r}. \]  

(272)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:

\[ h_w^* = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x^*_w - x^*_r}{\sqrt{W^*}} \right). \]  

(273)

Equating the groundwater heads at the wetland gives:

\[ -q_m \sinh \left( \frac{x^*_h - x^*_w}{\sqrt{W^*}} \right) = q_r \sinh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right), \]  

(274)

which can be rearranged to give an equation to solve for \( x^*_w \) using the arc sinh function:

\[ \sinh \left( \frac{x^*_h - x^*_w}{\sqrt{W^*}} \right) = \frac{-z^*}{q_m \left(1 - x^*_w \right) \sinh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right)}. \]  

(275)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma \left(z^*_w - h^*_w\right) = q_{w^*} - q_{w^*}^* \):

\[ \gamma \left(z^*_w - h^*_w\right) = q_r \cosh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right) - q_m \cosh \left( \frac{x^*_r - x^*_w}{\sqrt{W^*}} \right). \]  

(276)

The groundwater level between the highland and \( x^*_w \) can be calculated from:

\[ h^* = h_0^* - q_m x^*_w \quad \text{when} \quad 0 \leq x^*_w \leq x^*_w. \]  

(277)

The groundwater level between \( x^*_w \) and the wetland can be calculated from:

\[ h^* = z^* - q_m \sqrt{W^*} \sinh \left( \frac{x^*_w - x^*_h}{\sqrt{W^*}} \right) \quad \text{when} \quad x^*_w < x^*_h \leq x^*_w. \]  

(278)

The groundwater level between the wetland and \( x^*_w \) can be calculated from:

\[ h^* = z^* + q_r \sqrt{W^*} \sinh \left( \frac{x^*_r - x^*}{\sqrt{W^*}} \right) \quad \text{when} \quad x^*_w < x^* \leq x^*_r. \]  

(279)

The groundwater level between \( x^*_r \) and the river can be calculated from:
\[ h^* = q_r (1 - x^*) \quad \text{when} \quad x_{\text{crit}}^R < x^* \leq 1. \] (280)

**Case CEF - Highland and wetland groundwater levels below extinction depth, river level above the extinction depth**

The groundwater head at the edge of the highland, \( h_0^* \), is equal to:
\[ h_0^* = h_0^* + q_w x_w^*. \] (281)

The groundwater flux from the highland side into the wetland is given by:
\[ q_w^* = q_{\text{in}}. \] (282)

The groundwater head at the wetland, \( h_w^* \), from the highland side is equal to:
\[ h_w^* = h_0^* - q_w x_w^*. \] (283)

The groundwater flux from the wetland towards the river is given by:
\[ q_w^* = \sqrt{W^*} \cosh \left( \frac{x_{\text{crit}}^R}{\sqrt{W^*}} \right) \left( z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \right). \] (284)

The groundwater head at the wetland, \( h_w^* \), from the river side is equal to:
\[ h_w^* = z^* + \left[ z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \right] \left( \frac{1}{\sqrt{W^*}} \cosh \left( \frac{x_{\text{crit}}^R}{\sqrt{W^*}} \right) \right). \] (285)

At \( x^* = x_{\text{crit}}^R \), when \( h^* = z^* \), the equation to describe heads can be rearranged to give:
\[ \tanh \left( \frac{x_{\text{crit}}^R}{\sqrt{W^*}} \right) = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{z^* \cosh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \sinh \left( \frac{1}{\sqrt{W^*}} \right)}, \] (286)

which can be rearranged to give an equation for \( q_r \) in terms of \( x_{\text{crit}}^R \):
\[ q_r = \frac{z^*}{\sqrt{W^*} \tanh \left( \frac{1 - x_{\text{crit}}^R}{\sqrt{W^*}} \right)}. \] (287)

Equating the groundwater heads at the wetland gives:
\[ h_0^* - q_{\text{in}} x_w^* = z^* + \left[ z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right) \right] \left( \frac{1}{\sqrt{W^*}} \cosh \left( \frac{x_{\text{crit}}^R}{\sqrt{W^*}} \right) \right). \] (288)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, i.e. \( \gamma (z_w^* - h_w^*) = q_w^* - q_w^* \).
The Floodplain Risk Methodology (FRM)

\[ \gamma (z_w^* - h_w^*) = \frac{z^* \sinh \left( \frac{1}{\sqrt{W^*}} \right) - q_r \sqrt{W^*} \cosh \left( \frac{1}{\sqrt{W^*}} \right)}{\sqrt{W^*} \cosh \left( \frac{x_{crit}^R}{\sqrt{W^*}} \right)} - q_{in} . \] (289)

The groundwater level between the highland and the wetland can be calculated from:
\[ h_w^* = h_0^* - q_{in} x_w^* \quad \text{when} \quad 0 \leq x_w^* \leq x_w^* . \] (290)

The groundwater level between the wetland and \( x_{crit}^R \) can be calculated from:
\[ h_w^* = z^* - q_{in} ^* x_w^* \quad \text{when} \quad 0 \leq x_w^* \leq x_{crit}^R . \] (291)

The groundwater level between \( x_{crit}^R \) and the river can be calculated from:
\[ h_w^* = z^* - q_{in} ^* x_w^* \quad \text{when} \quad 0 \leq x_w^* \leq 1 . \] (292)

**Case CEG - Highland and wetland groundwater and river levels below the extinction depth**

The groundwater flux from the highland side into the wetland is given by:
\[ q_{w}^* = q_{in} . \] (293)

The groundwater level at the wetland, \( h_w^* \), from the highland side is equal to:
\[ h_w^* = h_0^* - q_{in} x_w^* . \] (294)

The groundwater flux from the wetland towards the river is given by:
\[ q_{w}^* = q_r . \] (295)

The groundwater level at the wetland, \( h_w^* \), from the river side is equal to:
\[ h_w^* = q_r (1 - x_r^* ) . \] (296)

Equating the groundwater levels at the wetland gives:
\[ h_0^* - q_{in} x_w^* = q_r (1 - x_r^* ) . \] (297)

Therefore, the head at the edge of the highland, \( h_0^* \), is equal to:
\[ h_0^* = q_r (1 - x_r^* ) + q_{in} x_w^* . \] (298)

Leakage at the wetland is given by the difference in groundwater fluxes into and out of the wetland, \( i.e., \gamma (z_w^* - h_w^*) = q_{w}^* - q_{w}^* \), therefore:
\[ \gamma (z_w^* - h_w^*) = q_r - q_{in} , \] (299)

and hence:
\[ q_r = \frac{q_{in} + \gamma z_w^*}{1 + \gamma (1 - x_w^* )} . \] (300)

The groundwater level between the highland and the wetland can be calculated from:
\[ h_w^* = h_0^* - q_{in} x_w^* \quad \text{when} \quad 0 \leq x_w^* \leq x_w^* . \] (301)

The groundwater level between the wetland and the river can be calculated from:
\[ h_w^* = q_r (1 - x_r^* ) \quad \text{when} \quad 0 \leq x_r^* \leq 1 . \] (302)
Scenario selection

In this section, we show the logic used to select the correct scenario based on the available data, solutions to scenarios and special cases (Figure A2). The first decision is whether the river level is above or below the vegetation rooting depth. As an example, if the river level is below the rooting depth, then Case CEG is used to determine whether the water table at the edge of the river valley is above or below the vegetation rooting depth. If the water table at the edge of the river valley is below the vegetation rooting depth, then Case CEG is used to determine whether the water table at the wetland is above or below the vegetation rooting depth. If the water table at the wetland is above the vegetation rooting depth, then Case CDG is used to solve for the water table at the edge of the river valley and at the wetland.

**River level below rooting depth (z*>0)**

- If $h^*_w \leq z^*$, use Case CEG to calculate $h^*_w$.
- If $h^*_w > z^*$, use Case CDG to calculate $h^*_w$.

**River level above rooting depth (z’<0)**

- If $q_w < q_w_{special}$, use Case CEF to calculate $q_w_{special}$.
- If $q_w > q_w_{special}$, use Case BEF to calculate $q_w_{special}$.

**Figure A2.** Decision tree used to determine which of the 12 scenarios needs to be solved.
Appendix B: FWIP Model GIS Fields and Visual Basic Code

Table B1. FWIP GIS field descriptions, typical values and units

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIVISIONID</td>
<td>The floodplain is divided into 3011 divisions that were ~250 m wide. These divisions were used to calculate floodplain impacts using the mathematical cross sectional model.</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>AREA</td>
<td>Floodplain division area.</td>
<td>2,247,473</td>
<td>m²</td>
</tr>
<tr>
<td>PERIMETER</td>
<td>Floodplain division perimeter.</td>
<td>16,111</td>
<td>m</td>
</tr>
<tr>
<td>HECTARES</td>
<td>Floodplain division area.</td>
<td>225</td>
<td>ha</td>
</tr>
<tr>
<td>RIV_KMS</td>
<td>Distance of floodplain division from the mouth of the River Murray.</td>
<td>632</td>
<td>km</td>
</tr>
<tr>
<td>RIV_ENT</td>
<td>Height of the river above sea level at entitlement flows (5,000 ML d⁻¹) at the division river km from backwater curves used to define model river level.</td>
<td>1925</td>
<td>cm</td>
</tr>
<tr>
<td>RIV_100</td>
<td>Height of the river at a flow of 100,000 ML d⁻¹ at the division river km from backwater curves used to define the floodplain surface in the model.</td>
<td>2150</td>
<td>cm</td>
</tr>
<tr>
<td>RIV_1956</td>
<td>Height of the river at the peak of the 1956 flood at the division river km from backwater curves used to define an alternate model floodplain surface.</td>
<td>2265</td>
<td>cm</td>
</tr>
<tr>
<td>OBS_SEEP</td>
<td>Observed seepage areas at the break of slope based on field work and anecdotal evidence.</td>
<td>0</td>
<td>'</td>
</tr>
<tr>
<td>SIMPACTSAL</td>
<td>An interpolated surface of groundwater salinity was obtained from SIMPACT (Miles et al., 2001). This is based on data from the SA Geodata Drillhole Database (<a href="https://info.pir.sa.gov.au/geoserver/sarig/frameSet.jsp">https://info.pir.sa.gov.au/geoserver/sarig/frameSet.jsp</a> ) maintained by Primary Industries and Resources South Australia, and represents the salinity of the regional aquifers beneath the highland, but not the floodplain aquifer.</td>
<td>27,750</td>
<td>mg L⁻¹</td>
</tr>
<tr>
<td>FIPRU_ID</td>
<td>FIP response unit, a unique id for floodplain units</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>LWMP</td>
<td>Land and water management plan area</td>
<td>MERRITI</td>
<td>-</td>
</tr>
<tr>
<td>REACH</td>
<td>Model reach where 0 = Mannum-Lock 1, 1 = Lock 1-2, 2 = Lock 2-3, 3 = Lock 3-4, 4 = Lock 4-5, 5 = Lock 5-6, 6 = Lock 6-model extent</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>PERMWATER</td>
<td>Indicates whether the wetland is permanently inundated. A value of zero indicates that the wetland is not permanently inundated, a value of one denotes that the wetland is permanently inundated.</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>FWIP</td>
<td>Indicates whether the division contains a wetland. A value of 0 indicates that the division does not contain a wetland, a value of 1 indicates that the division contains a permanent wetland, and a value of 11 that the division contains an ephemeral wetland.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>HIGHAREA</td>
<td>Vegetated division area between the highland and the wetland that is used to calculate the average rate of groundwater discharge as evapotranspiration through the floodplain between the highland and the wetland (HIGH_mm_d).</td>
<td>238,669</td>
<td>m²</td>
</tr>
<tr>
<td>WETAREA</td>
<td>Wetland division area that is used to calculate the average rate of groundwater movement into ('ve) or out of (+'ve) the wetland (WET_mm_d).</td>
<td>2,071,245</td>
<td>m²</td>
</tr>
</tbody>
</table>
### Table B1. continued

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIVERAREA</td>
<td>Vegetated division area between the wetland and the river that is used to calculate the average rate of groundwater discharge as evapotranspiration through the floodplain between the wetland and the river (RIVER_mm_d).</td>
<td>2,008,804</td>
<td>m²</td>
</tr>
<tr>
<td>NONVEGAREA</td>
<td>Non-vegetated area of the whole division that is assumed to be evenly distributed across the highland and river portions of the division when calculating average floodplain groundwater discharge rates.</td>
<td>53,459</td>
<td>m²</td>
</tr>
<tr>
<td><strong>Input parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDGE_L</td>
<td>Division width at the edge of the highland.</td>
<td>771</td>
<td>m</td>
</tr>
<tr>
<td>L</td>
<td>Division length. Distance from the highland edge to rivers edge calculated as the average of the length of the two sides of the divisions.</td>
<td>7551</td>
<td>m</td>
</tr>
<tr>
<td>HF</td>
<td>Height of the model floodplain surface above the river level (RIV_ENT).</td>
<td>2.25</td>
<td>m</td>
</tr>
<tr>
<td>Z_EXT</td>
<td>Extinction depth. This is the &quot;apparent&quot; groundwater depth at which capillary rise of saline groundwater to the surface driven by evapotranspiration is zero (i.e. the soil limited groundwater discharge by evapotranspiration only occurs when the water table is above this depth). The actual groundwater depth is somewhat deeper than this, as the analytical model assumes a linear relationship between evapotranspiration and groundwater depth. However, evapotranspiration is more closely represented by an inverse power function of groundwater depth (Warrick, 1988) and never declines to zero. Also, the analytical model assumes a flat floodplain surface whereas in reality there can be significant variations in surface topography.</td>
<td>2.0</td>
<td>m</td>
</tr>
<tr>
<td>A</td>
<td>The maximum transpiration rate of the vegetation and the soil limited evaporation rate determine the rate of evapotranspiration. This varies according to vegetation and soil type, with species such as Red Gum (Eucalyptus camaldulensis) having higher transpiration rates than Black Box (E. largiflorens). The original version of FIP used a single evapotranspiration rate of 0.0001 m d⁻¹.</td>
<td>0.0001</td>
<td>m d⁻¹</td>
</tr>
<tr>
<td>B</td>
<td>Floodplain aquifer thickness. This is known to vary spatially, however there are little data on which to base a varying surface. Therefore, a constant value of 10 m was assumed, which represents the saturated thickness of the floodplain aquifer below the Coonambidgal Clay layer. Implicit in this assumption is that the groundwater that is influencing evapotranspiration and seepage in the floodplain moves through the upper 10 m of the floodplain aquifer.</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>K</td>
<td>Floodplain aquifer hydraulic conductivity. Although the horizontal hydraulic conductivity of the floodplain aquifer is likely to vary spatially there are no data on which to base a varying surface. Therefore, a commonly reported value of 10 m/day is used.</td>
<td>10</td>
<td>m²d⁻¹</td>
</tr>
<tr>
<td>QIN</td>
<td>Groundwater inflows input per linear metre from the selected SIMPACT2 scenarios, including simulated flows under current irrigation and clearing (including the 'legacy of history', modelled inputs from irrigation developments over the past 100 years and resulting from native vegetation clearance), and at other points in time, e.g. 2050 and 2100.</td>
<td>0.09</td>
<td>m²d⁻¹</td>
</tr>
</tbody>
</table>
### Table B1. continued

<table>
<thead>
<tr>
<th>Field</th>
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</thead>
<tbody>
<tr>
<td>BETA</td>
<td>Wetland leakage parameter which represents the hydraulic conductivity of the soil layer between the wetland and the groundwater multiplied by the width of the wetland along the division flowpath and by the thickness of the soil layer. This is known to vary spatially, however there are little data available. Therefore, as a result of the model testing a constant value of either 10 or 65 m d⁻¹ was assumed for divisions with wetlands. Where there is no wetland, this value is set to zero.</td>
<td>0, 10, 65</td>
<td>m d⁻¹</td>
</tr>
<tr>
<td>ZW</td>
<td>Height of the wetland surface water level above sea level. In wetlands that were not permanently flooded, the minimum elevation from the Flood Inundation Model is used to determine the deepest point in the wetland. Where there is no wetland, this value is set to the river level.</td>
<td>1940</td>
<td>cm</td>
</tr>
<tr>
<td>RIVERENT_Z</td>
<td>Height of the wetland surface water level above (+ve) or below (-ve) the river level. Where there is no wetland, the wetland surface water level is set equal to the river level, i.e. this value is zero.</td>
<td>0.15</td>
<td>m</td>
</tr>
<tr>
<td>XW</td>
<td>Distance from the highland edge to the wetland. Where there is no wetland, this value is set to half the division length.</td>
<td>802</td>
<td>m</td>
</tr>
<tr>
<td><strong>Output results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOSTAR</td>
<td>Dimensionless floodplain groundwater level at the edge of the floodplain relative to river level. This is set to the floodplain surface (h₀ = 1) when seepage occurs and is negative when the water table is below river level.</td>
<td>0.819</td>
<td>-</td>
</tr>
<tr>
<td>HWSTAR</td>
<td>Dimensionless wetland groundwater level relative to river level. This is positive when the water table is above the river level and negative when it is below the river level.</td>
<td>0.371</td>
<td>-</td>
</tr>
<tr>
<td>XCRIT_H</td>
<td>The point at which the floodplain groundwater level crosses the model extinction depth between the highland and the wetland. Where the floodplain groundwater level at the highland and at the wetland is above the extinction depth this is set to equal the dimensionless distance to the wetland. Where the floodplain groundwater level at the highland and at the wetland is below the extinction depth this is set to equal the dimensionless distance to the highland, or zero.</td>
<td>0.106</td>
<td>-</td>
</tr>
<tr>
<td>XCRIT_R</td>
<td>The point at which the floodplain groundwater level crosses the model extinction depth between the wetland and the river. Where the floodplain groundwater level at the wetland and at the river is above the extinction depth this is set to equal the dimensionless distance to the river, or one. Where the floodplain groundwater level at the wetland and at the river is below the extinction depth this is set to equal the dimensionless distance to the wetland.</td>
<td>0.523</td>
<td>-</td>
</tr>
<tr>
<td>QMAX</td>
<td>The maximum groundwater flux that the floodplain aquifer can transmit without seepage. When seepage does not occur this value is set to -999.</td>
<td>-999</td>
<td>m²d⁻¹</td>
</tr>
</tbody>
</table>
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<tr>
<td>QS</td>
<td>The amount of groundwater that is discharged as seepage at the break of slope. When seepage occurs, it is calculated as the difference between the flux of groundwater entering the floodplain from the highland ($Q_{in}$) and the maximum groundwater flux that the floodplain aquifer can transmit without seepage ($Q_{max}$).</td>
<td>0.0</td>
<td>m$^2$d$^{-1}$</td>
</tr>
<tr>
<td>QET_H</td>
<td>The amount of groundwater discharged as evapotranspiration through the floodplain surface between the highland and the wetland. This occurs when the floodplain groundwater level between the highland and the wetland is above the model extinction depth.</td>
<td>0.04889</td>
<td>m$^2$d$^{-1}$</td>
</tr>
<tr>
<td>QLEAKAGE</td>
<td>The amount of groundwater flux into or out of the wetland. The direction of groundwater flow into or out of the wetland is determined by the groundwater levels in the wetland and floodplain aquifer.</td>
<td>-0.00004</td>
<td>m$^2$d$^{-1}$</td>
</tr>
<tr>
<td>QET_R</td>
<td>The amount of groundwater discharged as evapotranspiration through the floodplain surface between the wetland and the river. This occurs when the floodplain groundwater level between the wetland and the river is above the model extinction depth.</td>
<td>0.05941</td>
<td>m$^2$d$^{-1}$</td>
</tr>
<tr>
<td>QR</td>
<td>The amount of groundwater into or out of the river. The direction of groundwater flow into or out of the river is determined by the groundwater levels in the river and floodplain aquifer.</td>
<td>-0.01095</td>
<td>m$^2$d$^{-1}$</td>
</tr>
<tr>
<td>TONES_W</td>
<td>Tonnes of salt entering the wetland from the groundwater. It is calculated from the division values of $Q_{leakage}$, edge_L and SIMPACTSAL.</td>
<td>0.00000</td>
<td>tonnes d$^{-1}$</td>
</tr>
<tr>
<td>TONES_R</td>
<td>Tonnes of salt entering the river from the groundwater. When $Q_r$ is positive (i.e. flow towards the river) the amount of salt entering the river is calculated from the division value of $Q_r$, edge_L and SIMPACTSAL. When $Q_r$ negative it is set to zero.</td>
<td>0.00000</td>
<td>tonnes d$^{-1}$</td>
</tr>
<tr>
<td>TONES_FP</td>
<td>Tonnes of salt stored in the floodplain from the groundwater. It is calculated from the division values of $Q_{ET_H}$, $Q_{ET_R}$, edge_L and SIMPACTSAL.</td>
<td>0.00000</td>
<td>tonnes d$^{-1}$</td>
</tr>
<tr>
<td>TONES_Qin</td>
<td>Tonnes of salt entering the river valley. When $Q_{in}$ is positive (i.e. flow into the valley) the amount of salt entering the valley is calculated from the division values of $Q_{in}$, edge_L and SIMPACTSAL. It is set to zero when $Q_{in}$ is negative.</td>
<td>0.00000</td>
<td>tonnes d$^{-1}$</td>
</tr>
<tr>
<td>SCENARIO</td>
<td>The mathematical solution that was used by the model to calculate groundwater fluxes, where 1 = ADF, 2 = ADG, 3 = AEF, 4 = AEG, 5 = BDF, 6 = BDG, 7 = BEF, 8 = BEG, 9 = CDF, 10 = CDG, 11 = CEF, and 12 = CEG. Each letter refers to the groundwater level, i.e. at the break of slope (A) above the floodplain surface resulting in seepage; (B) below the floodplain surface, but within the extinction depth; or (C) below the extinction depth; at the wetland (D) above the extinction depth; or (E) below the extinction depth; and at the river (F) above the extinction depth; or (G) below the extinction depth.</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>ERROR</td>
<td>Denotes whether the model was able to find a solution for the input parameters. A value of zero denotes no error, a value of one denotes that a solution could not be found.</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
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<tr>
<td>XCRITSTAR</td>
<td>The proportion of floodplain through which groundwater is discharged. It is calculated from the XCRIT_H, XCRIT_R and SCENARIO fields and ranges from zero, where there is no groundwater discharge through the floodplain to one where the water table is within the vegetation rooting depth across the entire floodplain.</td>
<td>0.5</td>
<td>%</td>
</tr>
<tr>
<td>HIGH_mm_d</td>
<td>The flux of groundwater discharged through the vegetated area of the highland portion of the division as a proportion of the vegetated area of the whole division.</td>
<td>0.1579</td>
<td>mm d⁻¹</td>
</tr>
<tr>
<td>WET_mm_d</td>
<td>The flux of groundwater discharged through the wetland portion of the division.</td>
<td>-0.0002</td>
<td>mm d⁻¹</td>
</tr>
<tr>
<td>RIVER_mm_d</td>
<td>The flux of groundwater discharged through the vegetated area of the river portion of the division as a proportion of the vegetated area of the whole division.</td>
<td>0.0228</td>
<td>mm d⁻¹</td>
</tr>
<tr>
<td>NOVEG_mm_d</td>
<td>The flux of groundwater discharged through the vegetated area of the river portion of the division as a proportion of the vegetated area of the whole division.</td>
<td>0.0374</td>
<td>mm d⁻¹</td>
</tr>
</tbody>
</table>

FWIP Model Main Code Module

' Visual Basic for Applications
' Reads input from a form and calculates new Qs, Qet_H, Qet_R and Qr for each division
' FWIP - Floodplain Wetland Impact Project Model Main Code
' CSIRO Land and Water - Kate Holland, Ian Overton and Ian Jolly
' January 2005
'
' Model variables
Dim L, hf, zext, a, b, k, Qin, riverheight, beta, zw, xw As Double
Dim xstar, zwstar, xwstar, gamma, Wstar As Double
Dim hwstar, hostar, leakage, xcritstarH, xcritstarR As Double
Dim smallqin, smallqmax, smallqwstarminus, smallqwstarplus, smallqr As Double
Dim Qmax, Qs, Qet_H, Qe, Qet_R, Qr As Double
Dim propseepage, propET_H, propleakage, propET_R, propriver As Double
'
Dim acoshequation As Double
Dim xstar, x, h, hstar, Qo As Double
Dim xdiv, hdiv As Double
Dim scenario, divisionID As Integer
Dim smallqspecial, hostarspecial As Double
Dim smallqone, xzerostar, smallqo, smallqoguess, zeroguess As Double
Dim oneoversqrtWstar, oneminusxwstaroversqrtWstar, sqrtWstar, coshofoneoversqrtWstar
Dim coshofoneminusxwstaroversqrtWstar, sinhofoneoversqrtWstaroversqrtWstar As Double
Dim coshfoneminusxwstaroversqrtWstar, sinhfoneminusxwstaroversqrtWstaroversqrtWstar As Double
Dim coshxwstaroversqrtWstar, coshfxwstaroversqrtWstar, sinhfxwstaroversqrtWstaroversqrtWstar As Double
Dim tanhfxwstaroversqrtWstar, tanhfoneminusxwstaroversqrtWstar As Double
Dim num1, num2, num, numt, denom, wtsslope, junkdouble As Double
Dim errorm As Integer
The Floodplain Risk Methodology (FRM)

Dim high_mm_d, wet_mm_d, river_mm_d, nonveg_mm_d As Double
Dim tonnes_FP, tonnes_Qin As Double

' Parameters for solver

Dim icount As Integer
Dim accuracy, increment, value1, value2, result1, result2 As Double
Dim upper, middle, lower, resultU, resultM, resultL As Double

Private Sub ComboBox1_Change()
End Sub

Public Sub UserForm_Activate()
Dim pDoc As IMxDocument
Dim pLayer As IFeatureLayer
Dim pFLayer As IFeatureLayer
Dim pID As New UID
Dim pFeatureLayer As IFeatureLayer
Dim pDataset As IDataset
Dim pMap As IMap
Dim pMxDoc As IMxDocument
Dim LayerCount As Integer
Dim pUnknown As IUnknown
Dim pUnknownFL As IFeatureLayer
Dim pUnknownFC As IFeatureClass

Set pDoc = ThisDocument
i = 0
ComboBox1.Clear
' Add List of FWIP_scenario shapefiles from map
For i = 0 To pDoc.FocusMap.LayerCount - 1
    Set pUnknown = pDoc.FocusMap.Layer(i)
    If TypeOf pUnknown Is IFeatureLayer Then ' A FeatureLayer
        Set pUnknownFL = pUnknown
        Set pUnknownFC = pUnknownFL.FeatureClass
        If pUnknownFC.ShapeType = esriGeometryPolygon Then
            Set pLayer = pUnknown
            ComboBox1.AddItem (pLayer.Name)
        End If
    End If
Next

End Sub

' Load the FWIP scenario from file

Public Sub CommandButton19_Click()
Dim pEnumGxObject As IEnumGxObject
Dim pGxDataset As IGxDataset
Dim m_pGxDialog As IGxDialog
Dim m_pGxObjectFilter As IGxObjectFilter
Dim pFeatureLayer As IFeatureLayer
Dim FWIPFeatureClass2 As IFeatureClass

'Have the user select a shapefile

Set m_pGxDialog = New GxDialog
Set m_pGxObjectFilter = New GxFilterFeatureClasses
Set m_pGxDialog.ObjectFilter = m_pGxObjectFilter
m_pGxDialog.StartingLocation = "n:\FRM\SIMPACT_Scenarios\"
m_pGxDialog.Title = "Select a FWIP scenario:"
If m_pGxDialog.DoModalOpen(0, pEnumGxObject) Then
    pEnumGxObject.Reset
    Set pGxDataset = pEnumGxObject.Next
    Set FWIPFeatureClass2 = pGxDataset.Dataset
End If
ComboBox1.AddItem (FWIPFeatureClass2.AliasName)
ComboBox1.Value = FWIPFeatureClass2.AliasName

' Add the new scenario to the Map

Dim pWorkspaceFactory As IWorkspaceFactory
Dim pFeatureWorkspace As IFeatureWorkspace
Dim pMxDocument As IMxDocument
Dim pMap As IMap

Set pFeatureLayer = New FeatureLayer
Set pFeatureLayer.FeatureClass = FWIPFeatureClass2
pFeatureLayer.Name = FWIPFeatureClass2.AliasName
'Add the FeatureLayer to the focus map
Set pMxDocument = Application.Document
Set pMap = pMxDocument.FocusMap
pMap.AddLayer pFeatureLayer

End Sub

' Calculate Button on Main Form

Public Sub CommandButton1_Click()

'Set up variables

Dim pDoc As IMxDocument
Dim pLayer As IFeatureLayer
Dim pTable As ITable
' Dim pFc As IFeatureClass now as a global in Module1
Dim pFields As IFields
Dim pField As IField
Dim pFieldtoEdit As IField
Dim sFieldName As String
Dim pFLayer As IFeatureLayer
Dim pCur As IFeatureCursor
Dim pFeat As IFeature
Dim pRow As IRow
Dim pDataset As IDataset
Dim pseevalue As Single
Dim pqetvalue As Single
Dim ptest As IFeature
Dim pseepfield As IField
Dim saltload_W, saltload_R As Double
Dim regfledge As String
Dim edgeval As Integer
Dim totQr As Integer
Dim maxha, incha As Double
Dim xcritstar As Double

' Set some values

Set pDoc = ThisDocument
i = 0
seepcount = 0
etcount = 0
seeplength = 0
etarea_H = 0
etarea_W = 0
etarea_R = 0
modeledge_L = 0
vegarea = 0
totQr = 0
totsaltload_R = 0
totsaltload_W = 0
saltload_W = 0
saltload_R = 0
errorsum = 0
'
' Get the FWIP layer

Dim FWIPLayer As IFeatureLayer
Dim FWIPFeatureClass As IFeatureClass
Dim FWIPTable As ITable
Dim FWIPLayerText As String

FWIPLayerText = ComboBox1.Value

' Get FWIP scenario file
For i = 0 To pDoc.FocusMap.LayerCount - 1
    If TypeOf pDoc.FocusMap.Layer(i) Is IFeatureLayer Then
        If UCase(pDoc.FocusMap.Layer(i).Name) = UCase(FWIPLayerText) Then
            Set FWIPLayer = pDoc.FocusMap.Layer(i)
            Exit For
        End If
    End If
Next

Set pFc = FWIPLayer.FeatureClass

pID = "esriCore.Editor"
Set pEditor = Application.FindExtensionByCLSID(pID)

' Check if in editing mode already
If pEditor.EditState = esriStateEditing Then
Else ' Else start editing
    Set pDataset = FWIPLayer.FeatureClass
    pEditor.StartEditing pDataset.Workspace
End If

'Return a cursor for all the features
Set pTable = FWIPLayer
Set pCur = pTable.Update(Nothing, False)
Set pFeat = pCur.NextFeature

'---------------------------------------------------------------------------
' Loop through each record
'---------------------------------------------------------------------------
Dim pProgressDlgFact As IProgressDialogFactory
Dim pProgressDialog As IProgressDialog2
Dim pStepProgressor As IStepProgressor
Dim pTopoOperator As ITopologicalOperator2
Dim pTrackCancel As ITrackCancel
Dim lFeatureCount As Long
Dim lTotalFeatureCount As Long
Dim lEmptyFeatureCount As Long
'Exit if featureclass has no shapes
If lTotalFeatureCount = 0 Then
    MsgBox "No features found in shapefile. Exiting"
    Exit Sub
End If

'Show a progress dialog while we cycle through the features
Set pTrackCancel = New CancelTracker
Set pProgressDlgFact = New ProgressDialogFactory
Set pProgressDialog = pProgressDlgFact.Create(pTrackCancel, 0)
pProgressDialog.CancelEnabled = True
pProgressDialog.Title = "Calculating Groundwater Flows"
pProgressDialog.Animation = esriProgressGlobe
bContinue = True

'Loop through each record
While Not pFeat Is Nothing
    'Update progress dialog
    lFeatureCount = lFeatureCount + 1
    pStepProgressor.StepValue = 1
End If

'Set the properties of the Step Progressor
Set pStepProgressor = pProgressDialog
pStepProgressor.MinRange = 0
pStepProgressor.MaxRange = lTotalFeatureCount
pStepProgressor.StepValue = 1

While Not pFeat Is Nothing
    'Update progress dialog
    lFeatureCount = lFeatureCount + 1
    pStepProgressor.Message = lFeatureCount & " of " & lTotalFeatureCount & ", Divisions calculated"
    'Stop processing features if 'Cancel' button is selected
    bContinue = pTrackCancel.Continue
    pStepProgressor.Step

    'Get all the values needed from the table
    '
divisionID = pFeat.Value(2)
L = pFeat.Value(11)
hf = ((pFeat.Value(8) - pFeat.Value(7)) - 0.0001) / 100
zext = TextBox9.Value
a = TextBox11.Value
b = pFeat.Value(15)
k = pFeat.Value(16)
Qin = pFeat.Value(17)
riverheight = pFeat.Value(7) / 100
beta = pFeat.Value(18) * TextBox12.Value
zw = (pFeat.Value(19) - pFeat.Value(7)) / 100
xw = pFeat.Value(20)

'Calculate important constants

zstar = 1# - (zext / hf)
smallqin = Qin * L / (k * b * hf)
Wstar = (k * b * zext) / (a * L * L)

'New parameters for backwaters

zwstar = (pFeat.Value(19) - pFeat.Value(7)) / 100 / hf
xwstar = xw / L
gamma = (beta * hf) / (k * b)

sqrtWstar = Sqr(Wstar)
oneoversqrtWstar = 1# / Sqr(Wstar)
oneminusxwstaroversqrtWstar = (1# - xwstar) * oneoversqrtWstar
coshofoneoversqrtWstar = cosh(1# / sqrtWstar)
sinhofoneoversqrtWstar = sinh(1# / sqrtWstar)
coshofoneminusxwstaroversqrtWstar = cosh((1# - xwstar) * oneoversqrtWstar)
sinhofoneminusxwstaroversqrtWstar = sinh((1# - xwstar) * oneoversqrtWstar)
coshxwstaroversqrtWstar = cosh(xwstar * oneoversqrtWstar)
sinhxwstaroversqrtWstar = sinh(xwstar * oneoversqrtWstar)
tanhxwstaroversqrtWstar = tanh(xwstar * oneoversqrtWstar)
tanhofoneminusxwstaroversqrtWstar = tanh((1# - xwstar) * oneoversqrtWstar)

tanhofxwstaroversqrtWstar = tanh(xwstar * oneoversqrtWstar)

tanhofoneminusxwstaroversqrtWstar = tanh((1# - xwstar) * oneoversqrtWstar)

tanhofxwstaroversqrtWstar = tanh(xwstar * oneoversqrtWstar)

tanhofoneminusxwstaroversqrtWstar = tanh((1# - xwstar) * oneoversqrtWstar)

tanhofxwstaroversqrtWstar = tanh(xwstar * oneoversqrtWstar)

'Working parameters for solver

increment = 0.01
accuracy = 0.000001
icount = 0
result2 = 0
errorm = 0

' Need to decide which of the 12 scenarios you are dealing with:

1. ADF - Highland seepage, wetland within rooting depth, river within rooting depth
2. ADG - Highland seepage, wetland within rooting depth, river below rooting depth
3. AEF - Highland seepage, wetland below rooting depth, river within rooting depth
4. AEG - Highland seepage, wetland below rooting depth, river below rooting depth
5. BDF - Highland, wetland and river within rooting depth
6. BDG - Highland, wetland within rooting depth, river below rooting depth
'7. BEF - Highland within rooting depth, wetland below rooting depth, river within rooting depth
'8. BEG - Highland within rooting depth, wetland and river below rooting depth
'9. CDF - Highland below rooting depth, wetland and river within rooting depth
'10. CDG - Highland below rooting depth, wetland within rooting depth, river below rooting depth
'11. CEF - Highland and wetland groundwater below rooting depth, river within rooting depth
'12. CEG - Highland, wetland and river below rooting depth
'
Firstly, separate the scenarios into river level above, or river level below the rooting depth:
'River level below the rooting depth, zstar > 0.

If zstar > 0 Then
'River level below the rooting depth, zstar > 0
'Use Case CEG to calculate hostar
smallqr = (smallqin + gamma * zwstar) / (1# + gamma * (1# - xwstar))
hostar = 0
hostar = smallqr * (1# - xwstar) + smallqin * xwstar
'
If hostar > zstar Then
'Use special case A to calculate smallqin special A
smallqinspecial = ((zstar / (1# - xwstar)) - gamma * (zwstar - zstar)) * coshofxwstaroversqrtWstar
'smallqin", smallqin, "A: smallqinspecial ", smallqinspecial
'
If smallqin < smallqinspecial Then
'xcritstar is on the highland side of the wetland
'Therefore case EG. Use Case BEG to calculate hostar
'Use Case BEG to calculate hostar
scenario = 8
Call SolveBEG
'added loop into SolveBEG to send to Solve AEG if hostar>1
'
'If smallqin > smallqinspecial
Else
'xcritstar is on the river side of the wetland
'Therefore case DG. Use Case BDG to calculate hostar
'Use Case BDG to calculate hostar
scenario = 6
Call SolveBDG
'added loop into SolveBDG to send to Solve ADG if hostar>1
End If
'
'If hostar <= zstar Then
Else
'Use Case CEG to calculate hwstar
hwstar = hostar - smallqin * xwstar
'
If hwstar > zstar Then
'Case CDG
scenario = 10
Call SolveCDG

End If
'If hwstar <= zstar Then
Else
  'Case CEG'
  scenario = 12
  Call SolveCEG
End If
End If

'If zstar <= 0 Then
Else
  'River level above the rooting depth, zstar <= 0',
  'Use special case B to calculate smallqin special B'
  smallqinspecial = zstar / sqrtWstar / sinh((1# - xwstar) / sqrtWstar) - gamma * (zwstar - zstar)
  'smallqin", smallqin, "B: smallqinspecial ", smallqinspecial

If smallqin < smallqinspecial Then
  'xcritstar is on the river side of the wetland'
  'and Case CEF'
  scenario = 11
  Call SolveCEF

'If smallqin >= smallqinspecial Then
Else
  If smallqin < 0 Then
    'Use Case BDF to calculate hostar'
    smallqr = (gamma * (zwstar - zstar) * coshofoneoversqrtWstar + (zstar / sqrtWstar) * (sqrtWstar * gamma * coshofoneminusxwstaroversqrtWstar + sinhofoneoversqrtWstar) + smallqin) / (coshofoneoversqrtWstar + gamma * sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
    hostar = zstar + (-zstar * coshofoneminusxwstaroversqrtWstar + smallqr * sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqin * sqrtWstar * sinhofxwstaroversqrtWstar) / coshofxwstaroversqrtWstar

    If hostar > zstar Then
      'and Case BDF'
      scenario = 5
      Call SolveBDF
    Else
      'and Case CDF'
      scenario = 9
      Call SolveCDF
    End If

  'If smallqin >= 0 Then
Else
  'smallqin >= 0. Use Special Case C to calculate smallqinspecial C'
  smallqinspecial = cosh(xwstar / sqrtWstar) * (zstar / sqrtWstar / sinh((1# - xwstar) / sqrtWstar) - gamma * (zwstar - zstar))
  'smallqin ", smallqin, "C: smallqinspecial ", smallqinspecial

  If smallqin < smallqinspecial Then
    'Use Case CEF to calculate hostar'
    scenario = 11

Call SolveCEF
   ' SolveCEF will send it to SolveBEF if hostar > zstar and to SolveAEF if hostar > 1
   'If smallqin >= smallqinspecial Then
   Else
      ' Use Case BDF to calculate hostar and hwstar"
      smallqr = (gamma * (zwstar - zstar) * coshofoneoversqrtWstar + (zstar / sqrtWstar) * (sqrtWstar * gamma * coshofoneminusxwstaroversqrtWstar * coshofxwstaroversqrtWstar + sinhofoneoversqrtWstar) + smallqin) / (coshofoneoversqrtWstar * sinhofoneminusxwstaroversqrtWstar + gamma * sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
      hostar = zstar + (-zstar * coshofoneminusxwstaroversqrtWstar + smallqr * sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqin * sqrtWstar * sinhofxwstaroversqrtWstar) / coshofxwstaroversqrtWstar
      hwstar = zstar * (1 - coshofoneminusxwstaroversqrtWstar) + smallqr * sqrtWstar * sinhofoneminusxwstaroversqrtWstar
   
   If hwstar <= zstar Then
      ' Use Case BEF to calculate hostar"
      scenario = 7
      Call SolveBEF
      ' SolveBEF will send it to SolveAEF if hostar > 1
      'ElseIf hwstar > zstar And hostar <= zstar Then
      ' and Case CDF"
      scenario = 9
      Call SolveCDF
      ,
   'ElseIf hwstar > zstar And zstar < hostar <= 1 Then
   ' and Case BDF"
   ' scenario = 5
   ' Call SolveBDF
   ,
   ' ElseIf hwstar > zstar And hostar > 1 Then
   ' and Case ADF"
   ' scenario = 1
   ' Call SolveADF
   ,
   End If
   End If
   End If
   End If
   ' We should now have a solution and various fluxes etc calculated for all 12 scenarios
   SolvedIt:
   ' Print out key parameters and all of the fluxes out in both absolute and proportional terms
   If errorm = 1 Then
      xcritstarH = 0
      xcritstarR = xwstar
      smallqmax = -999
      Qmax = 0
   End If
Qs = 0
Qet_H = 0
Qleakage = 0
Qet_R = 0
Qr = 0
high_mm_d = 0
wet_mm_d = 0
river_mm_d = 0
saltload_R = 0
saltload_W = 0
xcritstar = 0
GoTo FinalCalcs
End If

If smallqmax = -999 Then
Qin = Qin
Qmax = -999
Qs = 0
Qet_H = (smallqin - smallqwstarminus) * k * b * hf / L
Qleakage = leakage * k * b * hf / L
Qet_R = (smallqwstarplus - smallqr) * k * b * hf / L
Qr = smallqr * k * b * hf / L
End If

If Qs < 0 Then Qs = 0

Using high_mm_d, wet_mm_d, and river_mm_d fields to store the proportion of the highland, wetland and river areas that have groundwater discharge.

If zstar > 0 Then 'river level below the rooting depth
  If hostar > zstar And hwstar > zstar Then 'ADG or BDG
    xcritstar = xcritstarR
    etarea_H = etarea_H + pFeat.Value(44)
    high_mm_d = pFeat.Value(44)
    etarea_R = etarea_R + pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
    river_mm_d = pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
  ElseIf hostar > zstar And hwstar < zstar Then 'AEG or BEG
    xcritstar = xcritstarH
    etarea_H = etarea_H + pFeat.Value(44) * xcritstarH / xwstar
    high_mm_d = pFeat.Value(44) * xcritstarH / xwstar
    etarea_R = etarea_R + 0
    river_mm_d = 0#
  ElseIf hostar < zstar And hwstar > zstar Then 'CDG
    xcritstar = xcritstarR - xcritstarH
    etarea_H = etarea_H + pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
    high_mm_d = pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
    etarea_R = etarea_R + pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
Else
  GoTo FinalCalcs
End If

If zstar < 0 Then 'river level above the rooting depth
  If hostar > zstar And hwstar > zstar Then 'BGD or CGD
    xcritstar = xcritstarH
    etarea_H = etarea_H + pFeat.Value(44) * xcritstarH / xwstar
    high_mm_d = pFeat.Value(44) * xcritstarH / xwstar
    etarea_R = etarea_R + pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
  ElseIf hostar < zstar And hwstar > zstar Then 'BDG or CDG
    xcritstar = xcritstarR - xcritstarH
    etarea_H = etarea_H + pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
    high_mm_d = pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
    etarea_R = etarea_R + pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
ElseIf hostar > zstar And hwstar < zstar Then 'AEG or BEG
  xcritstar = xcritstarH
  etarea_H = etarea_H + pFeat.Value(44) * xcritstarH / xwstar
  high_mm_d = pFeat.Value(44) * xcritstarH / xwstar
  etarea_R = etarea_R + 0
  river_mm_d = 0#
ElseIf hostar < zstar And hwstar > zstar Then 'CDG
  xcritstar = xcritstarR - xcritstarH
  etarea_H = etarea_H + pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
  high_mm_d = pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
  etarea_R = etarea_R + pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
Else
  GoTo FinalCalcs
End If
river_mm_d = pFeat.Value(46) * (xcritstarR - xwstar) / (1# - xwstar)
Else 'hostar <= zstar And hwstar <= zstar Then 'CEG
  xcritstar = 0
  etarea_H = etarea_H + 0
  high_mm_d = 0#
  etarea_R = etarea_R + 0
  river_mm_d = 0#
End If
Else 'If zstar <= 0 Then 'river level above the rooting depth
If hostar > zstar And hwstar > zstar Then 'ADF or BDF
  xcritstar = 1#
  etarea_H = etarea_H + pFeat.Value(44)
  high_mm_d = pFeat.Value(44)
  etarea_R = etarea_R + pFeat.Value(46)
  river_mm_d = pFeat.Value(46)
ElseIf hostar > zstar And hwstar < zstar Then 'AEF or BEF
  xcritstar = xcritstarH + 1# - xcritstarR
  etarea_H = etarea_H + pFeat.Value(44) * xcritstarH / xwstar
  high_mm_d = pFeat.Value(44) * xcritstarH / xwstar
  etarea_R = etarea_R + pFeat.Value(46) * (1# - xcritstarR) / (1# - xwstar)
  river_mm_d = pFeat.Value(46) * (1# - xcritstarR) / (1# - xwstar)
ElseIf hostar < zstar And hwstar > zstar Then 'CDF
  xcritstar = 1# - xcritstarH
  etarea_H = etarea_H + pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
  high_mm_d = pFeat.Value(44) * (xwstar - xcritstarH) / xwstar
  etarea_R = etarea_R + pFeat.Value(46)
  river_mm_d = pFeat.Value(46)
ElseIf hostar < zstar And hwstar < zstar Then 'CEF
  xcritstar = (1# - xcritstar_R) / (1# - xwstar)
  etarea_H = etarea_H + 0
  high_mm_d = 0#
  etarea_R = etarea_R + 0
  river_mm_d = 0#
Else
  xcritstar = 0
  etarea_H = etarea_H + 0
  high_mm_d = 0#
  etarea_R = etarea_R + 0
  river_mm_d = 0#
End If
End If

FinalCalcs:
' Store all of the fluxes in absolute terms
  saltload_R = Qr * pFeat.Value(10) / 1000 * pFeat.Value(32) / 1000
  saltload_W = -Qleakage * pFeat.Value(10) / 1000 * pFeat.Value(32) / 1000
  tonnes_FP = (Qs + Qet_H + Qet_R) * pFeat.Value(10) / 1000 * pFeat.Value(32) / 1000
  If Qin > 0 Then
    tonnes_Qin = Qin * pFeat.Value(10) / 1000 * pFeat.Value(32) / 1000
  Else
    tonnes_Qin = 0
  End If

'Use nonveg_mm_d to store total veg area with et per division

\[
\text{nonveg_mm_d} = \text{high_mm_d} + \text{wet_mm_d} + \text{river_mm_d}
\]

If saltload_R < 0 Then
   saltload_R = 0
End If

If saltload_W < 0 Then
   saltload_W = 0
End If

\[
\text{totsaltload}_R = \text{totsaltload}_R + \text{saltload}_R
\]
\[
\text{totsaltload}_W = \text{totsaltload}_W + \text{saltload}_W
\]

pFeat.Value(12) = hf
pFeat.Value(13) = zext
pFeat.Value(14) = a
pFeat.Value(15) = b
pFeat.Value(16) = k
pFeat.Value(21) = hostar
pFeat.Value(22) = hwstar
pFeat.Value(23) = xcritstarH
pFeat.Value(24) = xcritstarR
pFeat.Value(25) = Qmax
pFeat.Value(26) = Qs
pFeat.Value(28) = Qet_H
pFeat.Value(29) = Qleakage
pFeat.Value(30) = Qet_R
pFeat.Value(31) = Qr
pFeat.Value(33) = saltload_W
pFeat.Value(34) = saltload_R
pFeat.Value(35) = scenario
pFeat.Value(36) = errorm
pFeat.Value(37) = xcritstar
pFeat.Value(42) = zw
pFeat.Value(48) = high_mm_d
pFeat.Value(49) = wet_mm_d
pFeat.Value(50) = river_mm_d
pFeat.Value(51) = nonveg_mm_d
pFeat.Value(52) = tonnes_FP
pFeat.Value(53) = tonnes_Qin

errorsum = errorsum + errorm

If Qs > 0 Then
   seepcount = seepcount + 1
   seeplength = seeplength + pFeat.Value(10)
End If

\[
\text{modeledge}_L = \text{modeledge}_L + \text{pFeat.Value}(10)
\]

If Qleakage < 0 Then
   etarea_W = etarea_W + pFeat.Value(45)
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End If


' Save the new values

pFeat.Store

' Loop to next record

Set pFeat = pCur.NextFeature

' End While Loop

Wend

pProgressDialog.HideDialog
pDoc.ActiveView.Refresh
Unload Me

' Stop editing and save changes

pEditor.StopEditing True

' Report on number and size of seepage and ET areas

' Show results

FWIP_predictions.Show

End Sub

'------------------------------------------------------------------------------------

' The Subroutines

'------------------------------------------------------------------------------------

Private Sub SolveADF()

' 1. ADF - Highland seepage, wetland within rooting depth, river within rooting depth

' Solving for smallqr

For value1 = 99# To -99# Step -1#
    hwstar = zstar * (1# - coshofoneminusxwstaroversqrtWstar) + value1 * sqrtWstar * 
    sinhfoneminusxwstaroversqrtWstar
    smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar * 
    sinhfxwstaroversqrtWstar)
    result1 = -zstar / sqrtWstar * sinhfoneminusxwstaroversqrtWstar + value1 * 
    coshofoneminusxwstaroversqrtWstar + (1# - zstar) / sqrtWstar * sinhfxwstaroversqrtWstar - 
    smallqmax * coshofwxwstaroversqrtWstar - gamma * (zwstar - hwstar)
    icount = icount + 1
    If result1 = 0 Then
smallqr = value1
GoTo WriteResults
Elseif result2 * result1 < 0 Then
    GoTo FindAnswer
End If

result2 = result1

Next value1

FindAnswer:
upper = value1
lower = value1 + 1#
For icount = icount To 10000
    middle = (upper + lower) / 2
    ' Upper
    hwstar = zstar * (1# - coshofoneminusxwstaroversqrtWstar) + upper * sqrtWstar *
    sinhofoneminusxwstaroversqrtWstar
    smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar *
    sinhofxwstaroversqrtWstar)
    resultU = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + upper *
    coshofoneminusxwstaroversqrtWstar + (1# - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar -
    smallqmax * coshofxwstaroversqrtWstar - gamma * (zwstar - hwstar)
    ' Middle
    hwstar = zstar * (1# - coshofoneminusxwstaroversqrtWstar) + middle * sqrtWstar *
    sinhofoneminusxwstaroversqrtWstar
    smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar *
    sinhofxwstaroversqrtWstar)
    resultM = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + middle *
    coshofoneminusxwstaroversqrtWstar + (1# - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar -
    smallqmax * coshofxwstaroversqrtWstar - gamma * (zwstar - hwstar)
    ' Lower
    hwstar = zstar * (1# - coshofoneminusxwstaroversqrtWstar) + lower * sqrtWstar *
    sinhofoneminusxwstaroversqrtWstar
    smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar *
    sinhofxwstaroversqrtWstar)
    resultL = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + lower *
    coshofoneminusxwstaroversqrtWstar + (1# - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar -
    smallqmax * coshofxwstaroversqrtWstar - gamma * (zwstar - hwstar)
    If resultM >= -accuracy And resultM <= accuracy Then
        smallqr = middle
        icount = icount
        GoTo WriteResults
    Elself resultU * resultM < 0 Then
        lower = middle
    Elself resultL * resultM < 0 Then
        upper = middle
    End If
    If icount = 10000 Then
        errorm = 1
        'msgbox ("Iterations = 10,000")
        Exit Sub
    End If
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Next icount

WriteResults:
  hwstar = zstar * (1# - coshofoneminusxwstaroversqrtWstar) + smallqr * sqrtWstar * 
  sinhofoneminusxwstaroversqrtWstar
  hostar = 1
  leakage = gamma * (zwstar - hwstar)
  xcritstarH = xwstar
  xcritstarR = 1
  smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar * 
  sinhofxwstaroversqrtWstar)
  smallqwstarminus = -(1# - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar + smallqmax * 
  coshofxwstaroversqrtWstar
  smallqwstarplus = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqr * 
  coshofoneminusxwstaroversqrtWstar

' use value of hwstar from ADF to check if it is ADF or AEF

If hwstar < zstar Then
  scenario = 3
  Call SolveAEF
End If

End Sub
Private Sub SolveADG()

' 2. ADG - Highland seepage, wetland within rooting depth, river below rooting depth

' Solving for smallqr

For value1 = smallqin To 0 Step -0.001 * smallqin
  xcritstarR = 1# - zstar / value1
  hwstar = zstar + (value1 * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  smallqmax = (zstar - hwstar + (1# - zstar) * coshofxwstaroversqrtWstar) / (sqrtWstar * 
  sinhofxwstaroversqrtWstar)
  result1 = value1 * cosh((xcritstarR - xwstar) / sqrtWstar) + (1# - zstar) / sqrtWstar * 
  sinhofxwstaroversqrtWstar - smallqmax * coshofxwstaroversqrtWstar - gamma * (zwstar - 
  hwstar)

  icount = icount + 1

  If result1 = 0 Then
    smallqr = value1
    GoTo WriteResults
  ElseIf result2 * result1 < 0 Then
    GoTo FindAnswer
  End If

  result2 = result1

Next value1

FindAnswer:
upper = value1
lower = value1 + 0.001 * smallqin
For icount = icount To 10000
  ' Upper
  xcritstarR = 1# - zstar / upper
  hwstar = zstar + (upper * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  smallqmax = (zstar - hwstar + (1# - zstar) * coshfxwstaroversqrtWstar) / (sqrtWstar * sinhfxwstaroversqrtWstar)
  resultU = upper * cosh((xcritstarR - xwstar) / sqrtWstar) + (1# - zstar) / sqrtWstar * sinhfxwstaroversqrtWstar - smallqmax * coshfxwstaroversqrtWstar - gamma * (zwstar - hwstar)
  ' Middle
  xcritstarR = 1# - zstar / middle
  hwstar = zstar + (middle * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  smallqmax = (zstar - hwstar + (1# - zstar) * coshfxwstaroversqrtWstar) / (sqrtWstar * sinhfxwstaroversqrtWstar)
  resultM = middle * cosh((xcritstarR - xwstar) / sqrtWstar) + (1# - zstar) / sqrtWstar * sinhfxwstaroversqrtWstar - smallqmax * coshfxwstaroversqrtWstar - gamma * (zwstar - hwstar)
  ' Lower
  xcritstarR = 1# - zstar / lower
  hwstar = zstar + (lower * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  smallqmax = (zstar - hwstar + (1# - zstar) * coshfxwstaroversqrtWstar) / (sqrtWstar * sinhfxwstaroversqrtWstar)
  resultL = lower * cosh((xcritstarR - xwstar) / sqrtWstar) + (1# - zstar) / sqrtWstar * sinhfxwstaroversqrtWstar - smallqmax * coshfxwstaroversqrtWstar - gamma * (zwstar - hwstar)
  If resultM >= -accuracy And resultM <= accuracy Then
    smallqr = middle
    icount = icount
    GoTo WriteResults
  ElseIf resultU * resultM < 0 Then
    lower = middle
  ElseIf resultL * resultM < 0 Then
    upper = middle
  End If
  If icount = 10000 Then
    errorm = 1
    'msgbox("Iterations = 10,000")
    Exit Sub
  End If
Next icount

WriteResults:
  hwstar = zstar + (smallqr * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  hostar = 1
  leakage = gamma * (zwstar - hwstar)
  xcritstarH = xwstar
  xcritstarR = 1# - zstar / smallqr
  smallqmax = (zstar - hwstar + (1# - zstar) * coshfxwstaroversqrtWstar) / (sqrtWstar * sinhfxwstaroversqrtWstar)
smallqwstarminus = -(1# - zstar) / sqrtWstar * sinh(xwstaroversqrtWstar) + smallqmax * cosh(xwstaroversqrtWstar)
smallqwstarplus = smallqr * cosh((xcritstarR - xwstar) / sqrtWstar)

End Sub

Private Sub SolveAEF()
' 3. AEF - Highland seepage, wetland below rooting depth, river within rooting depth
' solving for xcritstarR
icount = 0
For value1 = xwstar To 1 Step 0.01
    smallqr = zstar / sqrtWstar / tanh((1# - value1) / sqrtWstar)
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(value1 / sqrtWstar)) * (xwstar - value1)
    xcritstarH = sqrtWstar * asinh((1# - zstar) * cosh(value1 / sqrtWstar) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar))
    result1 = (xcritstarH - xwstar) * (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(value1 / sqrtWstar)) * (xwstar - value1)
    icount = icount + 1
    If result1 = 0 Then
        xcritstarR = value1
        GoTo WriteResults
    ElseIf result2 * result1 < 0 Then
        GoTo FindAnswer
    End If
    result2 = result1
    Next value1
FindAnswer:
upper = value1
lower = value1 - 0.01
For icount = icount To 10000
    middle = (upper + lower) / 2
    ' Upper
    smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
    xcritstarH = sqrtWstar * asinh((1# - zstar) * cosh(upper / sqrtWstar) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar))
    resultU = (xcritstarH - xwstar) * (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
    ' Middle
    smallqr = zstar / sqrtWstar / tanh((1# - middle) / sqrtWstar)
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hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(middle / sqrtWstar)) * (xwstar - middle)
xcritstarH = sqrtWstar * asinh((1# - zstar) * cosh(middle / sqrtWstar) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar / cosh(middle / sqrtWstar)))
resultM = (xcritstarH - xwstar) * (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar) - ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar) / sqrtWstar / (zstar / sqrtWstar)) * (xwstar - middle)

Lower

smallqr = zstar / sqrtWstar / tanh((1# - lower) / sqrtWstar)
hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar) / sqrtWstar / cosh(lower / sqrtWstar)) * (xwstar - lower)
xcritstarH = sqrtWstar * asinh((1# - zstar) * cosh(lower / sqrtWstar) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar / cosh(lower / sqrtWstar)))
resultL = (xcritstarH - xwstar) * (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar) - ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar) / sqrtWstar / (zstar / sqrtWstar)) * (xwstar - lower)

If resultM >= -accuracy And resultM <= accuracy Then
    Form2.Print "Result", resultM, " xcritstarR ", middle
    xcritstarR = middle
    icount = icount
    GoTo WriteResults
ElseIf resultU * resultM < 0 Then
    lower = middle
ElseIf resultL * resultM < 0 Then
    upper = middle
End If

If icount = 10000 Then
    errorm = 1
    'msgbox ("Iterations = 10,000")
    Exit Sub
End If

Next icount

WriteResults:

hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar) / sqrtWstar / cosh(xcritstarR / sqrtWstar)) * (xwstar - xcritstarR)
hostar = 1
leakage = gamma * (zwstar - hwstar)
xcritstarH = sqrtWstar * asinh(((1# - zstar) * cosh(xcritstarR / sqrtWstar)) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar / cosh(xcritstarR / sqrtWstar)))
smallqmax = (1# - zstar) / sqrtWstar / tanh(xcritstarH * oneoversqrtWstar)
smallqr = zstar / sqrtWstar / tanh((1# - xcritstarR) / sqrtWstar)
smallqwstarminus = (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar)
smallqwstarplus = (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar / coshofoneoversqrtWstar) / sqrtWstar / cosh(xcritstarR / sqrtWstar)

End Sub

Private Sub SolveAEG()
4. AEG - Highland seepage, wetland below rooting depth, river below rooting depth

Solving for smallqr

For value1 = smallqin To 0 Step -0.1
  hwstar = value1 * (1# - xwstar)
  xcritstarH = (hwstar - zstar) / (value1 - gamma * (zwstar - hwstar)) + xwstar
  smallqmax = (1# - zstar) / tanh(xcritstarH * oneoversqrtWstar) / sqrtWstar
  result1 = value1 - (smallqmax / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)
  icount = icount + 1
  If result1 = 0 Then
    smallqr = value1
    GoTo WriteResults
  ElseIf result1 * result2 < 0 Then
    GoTo FindAnswer
  End If
  result2 = result1
Next value1

FindAnswer:
  upper = value1
  lower = value1 + 0.1
  For icount = icount To 10000
    middle = (upper + lower) / 2
    hwstar = upper * (1# - xwstar)
    xcritstarH = (hwstar - zstar) / (upper - gamma * (zwstar - hwstar)) + xwstar
    smallqmax = (1# - zstar) / tanh(xcritstarH * oneoversqrtWstar) / sqrtWstar
    resultU = upper - (smallqmax / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)
    hwstar = middle * (1# - xwstar)
    xcritstarH = (hwstar - zstar) / (middle - gamma * (zwstar - hwstar)) + xwstar
    smallqmax = (1# - zstar) / tanh(xcritstarH * oneoversqrtWstar) / sqrtWstar
    resultM = middle - (smallqmax / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)
    hwstar = lower * (1# - xwstar)
    xcritstarH = (hwstar - zstar) / (lower - gamma * (zwstar - hwstar)) + xwstar
    smallqmax = (1# - zstar) / tanh(xcritstarH * oneoversqrtWstar) / sqrtWstar
    resultL = lower - (smallqmax / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)
    If resultM >= -accuracy And resultM <= accuracy Then
      smallqr = middle
      icount = icount
      GoTo WriteResults
  End If
ElseIf resultU * resultM < 0 Then
    lower = middle
ElseIf resultL * resultM < 0 Then
    upper = middle
End If

If icount = 10000 Then
    errorm = 1
    'msgbox ("Iterations = 10,000")
    Exit Sub
End If

Next icount

WriteResults:
    hwstar = smallqr * (1# - xwstar)
    hostar = 1
    leakage = gamma * (zwstar - hwstar)
xcritstarH = (hwstar - zstar) / (smallqr - gamma * (zwstar - hwstar)) + xwstar
xcritstarR = xwstar
smallqmax = (1# - zstar) / tanh(xcritstarH * oneoversqrtWstar) / sqrtWstar
smallqstarminus = (1# - zstar) / sqrtWstar / sinh(xcritstarH / sqrtWstar)
    smallqstarplus = smallqr

End Sub

Private Sub SolveBDF()

' 5.  BDF - Highland, wetland and river within rooting depth

    smallqr = (gamma * (zwstar - zstar) * coshfoneoversqrtWstar + (zstar / sqrtWstar) * (sqrtWstar * gamma * coshfoneminusxwstaroversqrtWstar + sinhfoneoversqrtWstar) + smallqin) / (coshfoneoversqrtWstar + gamma * sqrtWstar * sinhfoneminusxwstaroversqrtWstar)
    hostar = zstar + (-zstar * coshfoneminusxwstaroversqrtWstar + smallqr * sqrtWstar * sinhfoneminusxwstaroversqrtWstar). / / coshfxwstaroversqrtWstar
    hwstar = zstar * (1 - coshfoneoversqrtWstar) + smallqr * sqrtWstar * sinhfoneminusxwstaroversqrtWstar
    xcritstarH = xwstar
    xcritstarR = 1#
    smallqmax = -999
    smallqstarminus = -(hostar - zstar) / sqrtWstar * sinh(xwstar / sqrtWstar) + smallqin * cosh(xwstar / sqrtWstar)
    smallqstarplus = -zstar / sqrtWstar * sinhfoneminusxwstaroversqrtWstar + smallqr * coshfoneminusxwstaroversqrtWstar

If hostar > 1 Then
    'Form2.Print "not case BDF, must be ADF"
    scenario = 1
    Call SolveADF
ElseIf hostar <= zstar Then
    scenario = 9
    Call SolveCDF
End If

End Sub

Private Sub SolveBDG()

' 6. BDG - Highland and wetland within rooting depth, river below rooting depth

' Solving for smallqr

num1 = zw * L / hf / (L - xw)
If num1 < smallqin Then
    num1 = smallqin
End If

For value1 = num1 To 0 Step (-0.01 * num1)
    xcritstarR = 1# - zstar / value1
    hwstar = zstar + (value1 * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
    hostar = zstar + (smallqin * sqrtWstar * sinh(xcritstarR - xwstar) / sqrtWstar) / cosh(xcritstarR - xwstar)
    result1 = value1 * cosh((xcritstarR - xwstar) / sqrtWstar) + (hostar - zstar) / sqrtWstar * sinhofxwstarsqrtWstar / coshofxwstarsqrtWstar - smallqin * coshofxwstarsqrtWstar - gamma * (zwstar - hwstar)
    icount = icount + 1
    If result1 = 0 Then
        smallqr = value1
        GoTo WriteResults
    ElseIf result2 * result1 < 0 Then
        GoTo FindAnswer
    End If
    result2 = result1
Next value1

FindAnswer:

upper = value1
lower = value1 + (0.01 * num1)
For icount = icount To 10000
    middle = (upper + lower) / 2
    ' Upper
    xcritstarR = 1# - zstar / upper
    hwstar = zstar + (upper * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
    hostar = zstar + (smallqin * sqrtWstar * sinh(xcritstarR - xwstar) / sqrtWstar) / cosh(xcritstarR - xwstar) / sqrtWstar + upper * sqrtWstar * sinhofxwstaroversqrtWstar + zstar - hwstar
    resultU = upper * cosh((xcritstarR - xwstar) / sqrtWstar) + (hostar - zstar) / sqrtWstar * sinh(xcritstarR - xwstar) / sqrtWstar / cosh(xcritstarR - xwstar) / sqrtWstar
    ' Middle
    xcritstarR = 1# - zstar / middle
    hwstar = zstar + (middle * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
    hostar = zstar + (smallqin * sqrtWstar * sinh(xcritstarR - xwstar) / sqrtWstar) / cosh(xcritstarR - xwstar) / sqrtWstar + middle * sqrtWstar * sinhofxwstaroversqrtWstar + zstar - hwstar
    resultM = middle * cosh((xs - xw) / sqrtWstar) + (hostar - zstar) / sqrtWstar * sinhofxwstarsqrtWstar / coshofxwstarsqrtWstar
Next icount
If result1 * result2 < 0 Then
    GoTo FindAnswer
End If

WriteResults:

smallqr = smallqr
End Sub
resultM = middle * cosh((xcritstarR - xwstar) / sqrtWstar) + (hostar - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar - smallqin * coshofxwstaroversqrtWstar - gamma * (zwstar - hwstar)
' Lower
xcritstarR = 1# - zstar / lower
hwstar = zstar + (lower * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
hostar = zstar + ((smallqin * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar)) + lower * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar)) / coshofxwstaroversqrtWstar
resultL = lower * cosh((xcritstarR - xwstar) / sqrtWstar) + (hostar - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar - smallqin * coshofxwstaroversqrtWstar - gamma * (zwstar - hwstar)
'
If resultM >= -accuracy And resultM <= accuracy Then
  smallqr = middle
  icount = icount
  GoTo WriteResults
ElseIf resultU * resultM < 0 Then
  lower = middle
ElseIf resultL * resultM < 0 Then
  upper = middle
End If
'
If icount = 10000 Then
  errorm = 1
  'msgbox("Iterations = 10,000")
  Exit Sub
End If
'
Next icount
'
WriteResults:
  hwstar = zstar + (smallqr * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar))
  hostar = zstar + ((smallqin * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar)) + smallqr * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar)) / coshofxwstaroversqrtWstar
  leakage = gamma * (zwstar - hwstar)
  xcritstarH = xwstar
  xcritstarR = 1# - zstar / smallqr
  smallqmax = -999
  smallqstarminus = -(hostar - zstar) / sqrtWstar * sinhofxwstaroversqrtWstar + smallqin * coshofxwstaroversqrtWstar
  smallqstarplus = smallqin * cos((xcritstarR - xwstar) / sqrtWstar)
  ' Need to send loop back to solve case ADG if hostar>1
If hostar > 1 Then
  'Form2.Print "not case BDG, must be ADG"
  scenario = 2
  Call SolveADG
End If
'
End Sub

Private Sub SolveBEF()
  
  ' 7. BEF - Highland within rooting depth, wetland below rooting depth, river within rooting depth
' Solving for xcritstarR

For value1 = xwstar To 1 Step 0.01
    smallqr = zstar / sqrtWstar / tanh((1# - value1) / sqrtWstar)
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(value1 / sqrtWstar)) * (xwstar - value1)
    acoshequation = ((smallqin * sqrtWstar * cosh(value1 / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(value1 / sqrtWstar))
    If acoshequation < 1 Then
        GoTo FindAnswer
    End If
    xcritstarH = sqrtWstar * acosh((smallqin * sqrtWstar * cosh(value1 / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(value1 / sqrtWstar))
    result1 = (xcritstarH - xwstar) * smallqin / cosh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar) * (xwstar - value1)
    icount = icount + 1
    If result1 = 0 Then
        xcritstarR = value1
    ElseIf result2 * result1 < 0 Then
        GoTo FindAnswer
    End If
    If value1 + 0.01 > 1# Then
        errorm = 1
        'MsgBox "value1 + 0.01 > 1#"
        Exit Sub
    End If
    result2 = result1
Next value1

FindAnswer:
upper = value1
lower = value1 - 0.01
For icount = icount To 1000
    middle = (upper + lower) / 2
    ' Upper
    smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
    acoshequation = ((smallqin * sqrtWstar * cosh(upper / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(upper / sqrtWstar))
    If acoshequation < 1 Then
        upper = middle
    ElseIf result2 * result1 < 0 Then
        GoTo FindAnswer
    End If
Next icount
smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
acoshequation = ((smallqin * sqrtWstar * cosh(upper / sqrtWstar)) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(upper / sqrtWstar)))

If acoshequation < 1 Then
  'middle value is too high as well, so set new upper = (middle + lower)/2
  value1 = (middle + lower) / 2
  upper = value1
  middle = (upper + lower) / 2
  smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
  acoshequation = ((smallqin * sqrtWstar * cosh(upper / sqrtWstar)) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(upper / sqrtWstar)))
  If acoshequation < 1 Then
    errorm = 1
    'MsgBox ("Cannot find a solution - 1")
    Exit Sub
  End If
Else
  'middle value is OK, so set new upper = (upper + middle) / 2
  value1 = middle + 0.25 * increment
  upper = value1
  middle = (upper + lower) / 2
  smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)
  acoshequation = ((smallqin * sqrtWstar * cosh(upper / sqrtWstar)) / (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar - gamma * (zwstar - hwstar) * sqrtWstar * cosh(upper / sqrtWstar)))
  If acoshequation < 1 Then
    errorm = 1
    'MsgBox ("Cannot find a solution - 2")
    Exit Sub
  End If
End If
resultU = (xcritstarH - xwstar) * smallqin / cosh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(upper / sqrtWstar)) * (xwstar - upper)

' Middle
smallqr = zstar / sqrtWstar / tanh((1# - middle) / sqrtWstar)
hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(middle / sqrtWstar)) * (xwstar - middle)
acoshequation = ((smallqin * sqrtWstar * cosh(middle / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(middle / sqrtWstar)) * (xwstar - middle)

If acoshequation < 1 Then
  'Form2.Print "Iteration ", icount, " acoshequationM ", acoshequation
errem = 1
  'MsgBox ("Cannot find a solution - 3")
  Exit Sub
End If

xcritstarH = sqrtWstar * acosh((smallqin * sqrtWstar * cosh(middle / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(middle / sqrtWstar))
resultM = (xcritstarH - xwstar) * smallqin / cosh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(middle / sqrtWstar)) * (xwstar - middle)

' Lower
smallqr = zstar / sqrtWstar / tanh((1# - lower) / sqrtWstar)
hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(lower / sqrtWstar)) * (xwstar - lower)
xcritstarH = sqrtWstar * acosh((smallqin * sqrtWstar * cosh(lower / sqrtWstar)) / (zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(lower / sqrtWstar))
resultL = (xcritstarH - xwstar) * smallqin / cosh(xcritstarH / sqrtWstar) - ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / sqrtWstar / cosh(lower / sqrtWstar)) * (xwstar - lower)

If resultM >= -accuracy And resultM <= accuracy Then
  xcritstarR = middle
  icount = icount
  GoTo WriteResults
ElseIf resultU * resultM < 0 Then
  lower = middle
ElseIf resultL * resultM < 0 Then
  upper = middle
End If

If icount = 1000 Then
  errorm = 1
  'MsgBox ("Iterations = 1,000")
  Exit Sub
End If

Next icount
WriteResults:
    smallqr = zstar / sqrtWstar / tanh((1 - xcritstarR) / sqrtWstar)
    hwstar = zstar + ((zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(xcritstarR / sqrtWstar)) * (xwstar - xcritstarR)
    xcritstarH = sqrtWstar * acosh(((smallqin * sqrtWstar * cosh(xcritstarR / sqrtWstar)) / (zstar - hwstar) * sqrtWstar * cosh(xcritstarR / sqrtWstar))))
    hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
    leakage = gamma * (zwstar - hwstar)
    smallqmax = -999
    smallqwstarminus = smallqin / sinh(xcritstarH / sqrtWstar)
    smallqwstarplus = (zstar * sinhofoneoversqrtWstar - smallqr * sqrtWstar * coshofoneoversqrtWstar) / sqrtWstar / cosh(xcritstarR / sqrtWstar)

    If hostar > 1 Then
        'Form2.Print "BEF hostar > 1, so Case AEF"
        scenario = 3
        Call SolveAEF
    End If
    
End Sub

Private Sub SolveBEG()
    
    ' 8. BEG - Highland within rooting depth, wetland and river below rooting depth
    
    ' Solving for smallqr
    
    For value1 = smallqin To 0 Step -0.01
        hwstar = value1 * (1 - xwstar)
        xcritstarH = (hwstar - zstar) / (value1 - gamma * (zwstar - hwstar)) + xwstar
        hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
        result1 = value1 - (smallqin / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)
    
        icount = icount + 1
        
        If result1 = 0 Then
            smallqr = value1
            GoTo WriteResults
        ElseIf result2 * result1 < 0 Then
            GoTo FindAnswer
        End If
    
        result2 = result1
    
    Next value1
    
    FindAnswer:
    upper = value1
    lower = value1 + 0.01
    For icount = icount To 10000
        middle = (upper + lower) / 2
        ' Upper
        hwstar = upper * (1 - xwstar)
xcritstarH = (hwstar - zstar) / (upper - gamma * (zwstar - hwstar)) + xwstar
hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
resultU = upper - (smallqin / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)

'Middle
hwstar = middle * (1# - xwstar)
xcritstarH = (hwstar - zstar) / (middle - gamma * (zwstar - hwstar)) + xwstar
hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
resultM = middle - (smallqin / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)

'Lower
hwstar = lower * (1# - xwstar)
xcritstarH = (hwstar - zstar) / (lower - gamma * (zwstar - hwstar)) + xwstar
hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
resultL = lower - (smallqin / cosh(xcritstarH * oneoversqrtWstar)) - gamma * (zwstar - hwstar)

If resultM >= -accuracy And resultM <= accuracy Then
    smallqr = middle
    icount = icount
    GoTo WriteResults
ElseIf resultU * resultM < 0 Then
    lower = middle
ElseIf resultL * resultM < 0 Then
    upper = middle
End If

If icount = 10000 Then
    errorm = 1
    'msgbox("Iterations = 10,000")
    Exit Sub
End If

Next icount

WriteResults:
    hwstar = smallqr * (1# - xwstar)
    hostar = smallqin * sqrtWstar * tanh(xcritstarH * oneoversqrtWstar) + zstar
    leakage = gamma * (zwstar - hwstar)
    xcritstarH = (hwstar - zstar) / (smallqr - gamma * (zwstar - hwstar)) + xwstar
    xcritstarR = xwstar
    smallqmax = -999
    smallqwstarminus = smallqin / cosh(xcritstarH / sqrtWstar)
    smallqwstarplus = smallqr

    ' Need to send loop back to solve case AEG if hostar>1
If hostar > 1 Then
    'msgbox("not case BEG, must be AEG")
    scenario = 4
    Call SolveAEG
End If

If xcritstarH < 0 Then
    errorm = 1
    'msgbox("Could not find a solution")
Private Sub SolveCDF()

' 9. CDF - Highland below rooting depth, wetland and river within rooting depth

' Solving for xcritstarH

For value1 = 0# To xwstar Step 0.1
    hwstar = zstar - smallqin * sqrtWstar * sinh((xwstar - value1) / sqrtWstar)
    smallqr = (zstar * coshofoneminusxwstaroversqrtWstar - smallqin * sqrtWstar * sinh((xwstar - value1) / sqrtWstar)) / (sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
    result1 = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqr * coshofoneminusxwstaroversqrtWstar - smallqin * cosh((xwstar - value1) / sqrtWstar) - gamma * (zwstar - hwstar)
    icount = icount + 1
    If result1 = 0 Then
        xcritstarH = value1
        GoTo WriteResults
    ElseIf result2 * result1 < 0 Then
        GoTo FindAnswer
    End If
    result2 = result1
Next value1

FindAnswer:
upper = value1
lower = value1 - 0.1
For icount = icount To 10000
    middle = (upper + lower) / 2
    ' Upper
    hwstar = zstar - smallqin * sqrtWstar * sinh((xwstar - upper) / sqrtWstar)
    smallqr = (zstar * coshofoneminusxwstaroversqrtWstar - smallqin * sqrtWstar * sinh((xwstar - upper) / sqrtWstar)) / (sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
    resultU = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqr * coshofoneminusxwstaroversqrtWstar - smallqin * cosh((xwstar - upper) / sqrtWstar) - gamma * (zwstar - hwstar)
    ' Middle
    hwstar = zstar - smallqin * sqrtWstar * sinh((xwstar - middle) / sqrtWstar)
    smallqr = (zstar * coshofoneminusxwstaroversqrtWstar - smallqin * sqrtWstar * sinh((xwstar - middle) / sqrtWstar)) / (sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
    resultM = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqr * coshofoneminusxwstaroversqrtWstar - smallqin * cosh((xwstar - middle) / sqrtWstar) - gamma * (zwstar - hwstar)
    ' Lower
    hwstar = zstar - smallqin * sqrtWstar * sinh((xwstar - lower) / sqrtWstar)
    smallqr = (zstar * coshofoneminusxwstaroversqrtWstar - smallqin * sqrtWstar * sinh((xwstar - lower) / sqrtWstar)) / (sqrtWstar * sinhofoneminusxwstaroversqrtWstar)
    resultL = -zstar / sqrtWstar * sinhofoneminusxwstaroversqrtWstar + smallqr * coshofoneminusxwstaroversqrtWstar - smallqin * cosh((xwstar - lower) / sqrtWstar) - gamma * (zwstar - hwstar)
    If resultU * resultM * resultL < 0 Then
        GoTo FindAnswer
    End If
    If abs(resultU - resultM) < 0.0001 Then
        upper = middle
    ElseIf abs(resultM - resultL) < 0.0001 Then
        lower = middle
    Else
        middle = (upper + lower) / 2
    End If
Next icount
End Sub
resultL = -zstar / sqrtWstar * sinhOfOneMinusXwstar / sqrtWstar + smallqr * coshOfOneMinusXwstar / sqrtWstar - smallqin * cosh((xwstar - lower) / sqrtWstar) - gamma * (zwstar - hwstar)

If resultM >= -accuracy And resultM <= accuracy Then
    xcritstarH = middle
    icount = icount
    GoTo WriteResults
ElseIf resultU * resultM < 0 Then
    lower = middle
ElseIf resultL * resultM < 0 Then
    upper = middle
End If
Next icount

WriteResults:
    hwstar = zstar - smallqin * sqrtWstar * sinh((xwstar - xcritstarH) / sqrtWstar)
    smallqr = (zstar * sinhOfOneMinusXwstar / sqrtWstar - smallqin * sqrtWstar * sinh((xwstar - xcritstarH) / sqrtWstar)) / (sqrtWstar * sinhOfOneMinusXwstar / sqrtWstar)
    xcritstarR = 1#
    hostar = zstar + smallqin * xcritstarH
    leakage = gamma * (zwstar - hwstar)
    smallqmax = -999
    smallqwstarminus = smallqin * cosh((xwstar - xcritstarH) / sqrtWstar)
    smallqwstarplus = -zstar / sqrtWstar * sinhOfOneMinusXwstar / sqrtWstar + smallqr * coshOfOneMinusXwstar / sqrtWstar

End Sub

Private Sub SolveCDG()

    ' 10. CDG - Highland below rooting depth, wetland within rooting depth, river below rooting depth
    ' Solving for xcritstarR
    For value1 = xwstar To 1 Step 0.1
        smallqr = zstar / (1 - value1)
        hwstar = zstar + smallqr * sqrtWstar * sinh((value1 - xwstar) / sqrtWstar)
        xcritstarH = xwstar - sqrtWstar * asinh(-smallqr / smallqin * sinh((value1 - xwstar) / sqrtWstar))
        result1 = smallqr * cosh((value1 - xwstar) / sqrtWstar) - smallqin * cosh((xwstar - xcritstarH) / sqrtWstar) - gamma * (zwstar - hwstar)
        icount = icount + 1
        If result1 = 0 Then
            xcritstarR = value1
            GoTo WriteResults
        ElseIf result2 * result1 < 0 Then
            GoTo FindAnswer
        End If
    Next value1

    result2 = result1
Next value1
'

FindAnswer:
upper = value1
lower = value1 - 0.1
For icount = icount To 100
    middle = (upper + lower) / 2
    ' Upper
    smallqr = zstar / (1 - upper)
    hwstar = zstar + smallqr * sqrtWstar * sinh((upper - xwstar) / sqrtWstar)
    xcritstarH = xwstar - sqrtWstar * asinh(-smallqr / smallqin * sinh((upper - xwstar) / sqrtWstar))
    resultU = smallqr * cosh((upper - xwstar) / sqrtWstar) - smallqin * cosh((xwstar - xcritstarH) / sqrtWstar)
    ' Middle
    smallqr = zstar / (1 - middle)
    hwstar = zstar + smallqr * sqrtWstar * sinh((middle - xwstar) / sqrtWstar)
    xcritstarH = xwstar - sqrtWstar * asinh(-smallqr / smallqin * sinh((middle - xwstar) / sqrtWstar))
    resultM = smallqr * cosh((middle - xwstar) / sqrtWstar) - smallqin * cosh((xwstar - xcritstarH) / sqrtWstar)
    ' Lower
    smallqr = zstar / (1 - lower)
    hwstar = zstar + smallqr * sqrtWstar * sinh((lower - xwstar) / sqrtWstar)
    xcritstarH = xwstar - sqrtWstar * asinh(-smallqr / smallqin * sinh((lower - xwstar) / sqrtWstar))
    resultL = smallqr * cosh((lower - xwstar) / sqrtWstar) - smallqin * cosh((xwstar - xcritstarH) / sqrtWstar)
    If resultU >= -accuracy And resultU <= accuracy Then
        xcritstarR = middle
        GoTo WriteResults
    ElseIf resultU * resultM < 0 Then
        lower = middle
    ElseIf resultL * resultM < 0 Then
        upper = middle
    End If
    If icount = 10000 Then
        errorm = 1
        'msgbox("Iterations = 10,000")
        Exit Sub
    End If

Next icount
'

WriteResults:
    smallqr = zstar / (1 - xcritstarR)
    hwstar = zstar + smallqr * sqrtWstar * sinh((xcritstarR - xwstar) / sqrtWstar)
    xcritstarH = xwstar - sqrtWstar * asinh(-smallqr / smallqin * sinh((xcritstarR - xwstar) / sqrtWstar))
    hostar = zstar + smallqin * xcritstarH
    leakage = gamma * (zwstar - hwstar)
    smallqmax = -999
    smallqwstarminus = smallqin * cosh((xwstar - xcritstarH) / sqrtWstar)
The Floodplain Risk Methodology (FRM)

smallqwstarplus = smallqr * cosh((xcritstarR - xwstar) / sqrtWstar)

End Sub

Private Sub SolveCEF()
' 11. CEF - Highland and wetland groundwater below rooting depth, river within rooting depth
' Solving for xcritstarR

For value1 = xwstar To 1# Step 0.01 * xwstar
  hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / (sqrtWstar * cosh(value1 / sqrtWstar))) * (xwstar - value1)
  smallqr = zstar / sqrtWstar / tanh((1# - value1) / sqrtWstar)
  result1 = ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / (sqrtWstar * cosh(value1 / sqrtWstar))) - smallqin - gamma * (zwstar - hwstar)
  icount = icount + 1
  If result1 = 0 Then
    xcritstarR = value1
    GoTo WriteResults
  ElseIf result2 * result1 < 0 Then
    GoTo FindAnswer
  End If
  If value1 + 0.01 >= 1# Then
    errorm = 1
    'MsgBox ("value1 + 0.01 > 1#")
    Exit Sub
  End If
  result2 = result1
Next value1

FindAnswer:
  upper = value1
  lower = value1 - 0.01 * xwstar
  For icount = icount To 100
    middle = (upper + lower) / 2
    If upper = middle Then
      scenario = 7
      Call SolveBEF
    End If
  ' Upper
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / (sqrtWstar * cosh(upper / sqrtWstar))) * (xwstar - upper)
    smallqr = zstar / sqrtWstar / tanh((1# - upper) / sqrtWstar)
    resultU = ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / (sqrtWstar * cosh(upper / sqrtWstar))) - smallqin - gamma * (zwstar - hwstar)
  ' Middle
    hwstar = zstar + ((zstar * sinhfoneoversqrtWstar - smallqr * sqrtWstar * coshfoneoversqrtWstar) / (sqrtWstar * cosh(middle / sqrtWstar))) * (xwstar - middle)
  Next value1

smallqr = zstar / sqrtWstar / tanh((1# - middle) / sqrtWstar)
resultM = ((zstar * sinh(1/# / sqrtWstar) - smallqr * sqrtWstar * cosh(1/# / sqrtWstar)) / (sqrtWstar * cosh(middle / sqrtWstar))) - smallqin - gamma * (zwstar - hwstar)
  ' Lower
hwstar = zstar + ((zstar * sinh(1/# / sqrtWstar) - smallqr * sqrtWstar * cosh(1/# / sqrtWstar)) / (sqrtWstar * cosh(lower / sqrtWstar))) * (xwstar - lower)
smallqr = zstar / sqrtWstar / tanh((1# - lower) / sqrtWstar)
resultL = ((zstar * sinh(1/# / sqrtWstar) - smallqr * sqrtWstar * cosh(1/# / sqrtWstar)) / (sqrtWstar * cosh(lower / sqrtWstar))) - smallqin - gamma * (zwstar - hwstar)

If resultM >= -accuracy And resultM <= accuracy Then
  xcritstarR = middle
  GoTo WriteResults
ElseIf resultU * resultM < 0 Then
  lower = middle
ElseIf resultL * resultM < 0 Then
  upper = middle
End If

If icount = 100 Then
  errorm = 1
  'msgbox(“Iterations = 10,000”) 
  Exit Sub
End If

Next icount

WriteResults:
  hwstar = zstar + ((zstar * sinh(1/# / sqrtWstar) - smallqr * sqrtWstar * cosh(1/# / sqrtWstar)) / (sqrtWstar * cosh(xcritstarR / sqrtWstar))) * (xwstar - xcritstarR)
  xcritstarH = xwstar
  hostar = hwstar + smallqin * xwstar
  leakage = gamma * (zwstar - hwstar)
  smallqmax = -999
  smallqwstarminus = smallqin
  smallqwstarplus = (zstar * sinh(1/# / sqrtWstar) - smallqr * sqrtWstar * cosh(1/# / sqrtWstar)) / (sqrtWstar * cosh(xcritstarR / sqrtWstar))

If hostar > zstar Then
  scenario = 7
  Call SolveBEF
End If

End Sub

Private Sub SolveCEG()

  ' 12. CEG - Highland, wetland and river below rooting depth

  WriteResults:
  smallqr = (smallqin + gamma * zwstar) / (1# + gamma * (1# - xwstar))
  hostar = smallqr * (1# - xwstar) + smallqin * xwstar
  hwstar = hostar - smallqin * xwstar
leakage = gamma * (zwstar - hwstar)
xcritstarH = 0#
xcritstarR = xwstar
smallqmax = -999
smallqwstarminus = smallqin
smallqwstarplus = smallqr
,
End Sub

Function sinh(x As Double) As Double
    sinh = (Exp(x) - Exp(-x)) / 2#
End Function

Function cosh(x As Double) As Double
    If x > 500 Then
        x = 500#
    ElseIf x < -500 Then
        x = -500#
    End If
    cosh = (Exp(x) + Exp(-x)) / 2#
End Function

Function tanh(x As Double) As Double
    If x > 500 Then
        x = 500#
    ElseIf x < -500 Then
        x = -500#
    End If
    tanh = (Exp(x) - Exp(-x)) / (Exp(x) + Exp(-x))
End Function

Function ln(x As Double) As Double
    ln = Log(x) / Log(Exp(1#))
End Function

Function acosh(x As Double) As Double
    acosh = 2# * ln(Sqr((x + 1#) / 2#) + Sqr((x - 1#) / 2#))
End Function

Function asinh(x As Double) As Double
    asinh = ln(x + Sqr(((x * x) + 1#)))
End Function

Private Sub CommandButton10_Click()
    reachparams.Show
End Sub

'Load SIMPACT scenario
Private Sub CommandButton11_Click()
    Dim pDoc As IMxDocument
    Dim pLayer As ILayer
    Dim SIMPACTFeatureClass, SIMPACTFeatureClass2 As IFeatureClass
Dim pFeatureLayer As IFeatureLayer
Dim i As Integer
Dim SIMPACTFeatureClassText As String
Dim SIMPACTLayer As ILayer
Dim pEnumGxObject As IEnumGxObject
Dim pGxDataset As IGxDataset
Dim m_pGxDialog As IGxDialog
Dim m_pGxObjectFilter As IGxObjectFilter

'Have the user select a shapefile
Set m_pGxDialog = New GxDialog
Set m_pGxObjectFilter = New GxFilterShapefiles
Set m_pGxDialog.ObjectFilter = m_pGxObjectFilter
m_pGxDialog.StartingLocation = "n:\FRM\SIMPACT_Scenarios\"
m_pGxDialog.Title = "Select a SIMPACT scenario:" If m_pGxDialog.DoModalOpen(0, pEnumGxObject) Then
    pEnumGxObject.Reset
    Set pGxDataset = pEnumGxObject.Next
    Set SIMPACTFeatureClass2 = pGxDataset.Dataset
End If

' Add the new scenario to the Map

Dim pWorkspaceFactory As IWorkspaceFactory
Dim pFeatureWorkspace As IFeatureWorkspace
Dim pMxDocument As IMxDocument
Dim pMap As IMap

Set pFeatureLayer = New FeatureLayer
Set pFeatureLayer.FeatureClass = SIMPACTFeatureClass2
pFeatureLayer.Name = SIMPACTFeatureClass2.AliasName
'Add the FeatureLayer to the focus map
Set pMxDocument = Application.Document
Set pMap = pMxDocument.FocusMap
pMap.AddLayer pFeatureLayer

End Sub

Private Sub CommandButton12_Click()
reachparams.Show
End Sub

Private Sub CommandButton13_Click()
reachparams.Show
End Sub

Private Sub CommandButton14_Click()
divisionset.Show
End Sub
Private Sub CommandButton15_Click()
    divisionset.Show
End Sub

Private Sub CommandButton16_Click()
    reachparams.Show
End Sub

Private Sub CommandButton17_Click()
    divisionset.Show
End Sub

Private Sub CommandButton18_Click()
    vegparams.Show
End Sub

' Cancel Button on Main Form
Private Sub CommandButton2_Click()
    Unload Me
End Sub

Private Sub Frame3_Click()
End Sub

Private Sub regfledgecombo_Change()
    regfledge = regfledgecombo.Text
End Sub

Private Sub TextBox12_Change()
End Sub

Private Sub TextBox9_Change()
End Sub

Private Sub UserForm_Initialize()
    regfledgecombo.AddItem "1956 Flood Height"
    regfledgecombo.AddItem "100 GL/Day Flood Height"
regfledgecombo.ListIndex = 1

End Sub

**FWIP Model Predictions Module**

' Produce summary table and give option to save FWIP scenario

Option Explicit

Private m_pGxDialog As IGxDialog
Private m_pGxObjectFilter As IGxObjectFilter

Private Sub CommandButton2_Click()
Dim pFeature As IFeature
Dim plnFeatureClass As IFeatureClass
Dim pFeatureCursor As IFeatureCursor
Dim pGeometry As IGeometry
Dim plnInsertFeatureBuffer As IFeatureBuffer
Dim plnInsertFeatureCursor As IFeatureCursor
Dim plnOutFeatureClass As IFeatureClass
Dim pProgressDlgFact As IPersistentDialogFactory
Dim pProgressDialog As IPersistentDialog2
Dim pStepProgressor As IStepProgressor
Dim pTopoOperator As ITopologicalOperator2
Dim pTrackCancel As ITrackCancel

Dim bContinue As Boolean
Dim lFeatureCount As Long
Dim lTotalFeatureCount As Long
Dim lEmptyFeatureCount As Long
Dim sFinalMessage As String

On Error GoTo ErrorHandler

Set plnFeatureClass = GetShapefile
If plnFeatureClass Is Nothing Then
    MsgBox "Error selecting Shapefile. Exiting."
    Exit Sub
End If

' Exit if featureclass has no shapes
lTotalFeatureCount = plnFeatureClass.FeatureCount(Nothing)
If lTotalFeatureCount = 0 Then
    MsgBox "No features found in shapefile. Exiting"
    Exit Sub
End If

' Create a new Shapefile
Set plnOutFeatureClass = CreateNewShapefile(plnFeatureClass)
If plnOutFeatureClass Is Nothing Then
    MsgBox "Error creating new Shapefile, check folder permissions"
    Exit Sub
End If

*Exit if featureclass has no shapes
lTotalFeatureCount = plnOutFeatureClass.FeatureCount(Nothing)
If lTotalFeatureCount = 0 Then
    MsgBox "No features found in shapefile. Exiting"
    Exit Sub
End If

*Create a new Shapefile
Set plnOutFeatureClass = CreateNewShapefile(plnFeatureClass)
If plnOutFeatureClass Is Nothing Then
    MsgBox "Error creating new Shapefile, check folder permissions"
    Exit Sub

End If

'Show a progress dialog while we cycle through the features
Set pTrackCancel = New CancelTracker
Set pProgressDlgFact = New ProgressDialogFactory
Set pProgressDialog = pProgressDlgFact.Create(pTrackCancel, 0)
pProgressDialog.CancelEnabled = True
pProgressDialog.Title = "Saving New Scenario"
pProgressDialog.Animation = esriDownloadFile
bContinue = True

'Set the properties of the Step Progressor
Set pStepProgressor = pProgressDialog
pStepProgressor.MinRange = 0
pStepProgressor.MaxRange = lTotalFeatureCount
pStepProgressor.StepValue = 1

'Create an insert cursor
Set plnInsertFeatureCursor = pOutFeatureClass.Insert(True)
Set plnInsertFeatureBuffer = pOutFeatureClass.CreateFeatureBuffer

'Loop through all features in the feature class, correcting each one, and write it out to the new shapefile
Set pFeatureCursor = plnFeatureClass.Search(Nothing, False)
Set pFeature = pFeatureCursor.NextFeature
Do While Not pFeature Is Nothing
'Update progress dialog
lFeatureCount = lFeatureCount + 1
pStepProgressor.Message = lFeatureCount & " of " & lTotalFeatureCount & " Divisions saved"
'Stop processing features if 'Cancel' button is selected
bContinue = pTrackCancel.Continue
pStepProgressor.Step
If Not bContinue Then Exit Do

'If the feature has an invalid shape, create a new empty one
If pFeature.Shape Is Nothing Then
    Set pFeature.Shape = CreateNewGeometry(pOutFeatureClass)
End If
'Simplify each feature and insert into new feature class
Set pTopoOperator = pFeature.Shape
InsertFeature plnInsertFeatureCursor, plnInsertFeatureBuffer, pFeature, pTopoOperator
'Count number of empty features
Set pGeometry = pTopoOperator
If pGeometry.IsEmpty Then
    lEmptyFeatureCount = lEmptyFeatureCount + 1
End If
'Retrieve next feature
Set pFeature = pFeatureCursor.NextFeature
Loop

pProgressDialog.HideDialog
Set plnInsertFeatureBuffer = Nothing
Set plnInsertFeatureCursor = Nothing
'Recreate indexes on new Shapefile
CreateIndexes pInFeatureClass, pOutFeatureClass

'MsgBox sFinalMessage
Set m_pGxObjectFilter = Nothing
Set m_pGxDialog = Nothing

' Add the new scenario to the Map

Dim pWorkspaceFactory As IWorkspaceFactory
Dim pFeatureWorkspace As IFeatureWorkspace
Dim pFeatureLayer As IFeatureLayer
Dim pMxDocument As IMxDocument
Dim pMap As IMap

Set pFeatureLayer = New FeatureLayer
Set pFeatureLayer.FeatureClass = pOutFeatureClass
pFeatureLayer.Name = pOutFeatureClass.AliasName

'Add the FeatureLayer to the focus map
Set pMxDocument = Application.Document
Set pMap = pMxDocument.FocusMap
pMap.AddLayer pFeatureLayer

Unload Me

Exit Sub 'Exit to avoid error handler

ErrorHandler:
    MsgBox "An unexpected error occurred." & vbCrLf & vbCrLf & _
    IFeatureCount & " Features processed." & vbCrLf

Unload Me

End Sub

Private Function GetShapefile() As IFeatureClass
    Dim pEnumGxObject As IEnumGxObject
    Dim pFeatureClass As IFeatureClass
    Dim pGxDataset As IGxDataset

    On Error GoTo ErrorHandler

    'Have the user select a shapefile
    Set m_pGxDialog = New GxDialog
    Set m_pGxObjectFilter = New GxFilterShapefiles

    Set m_pGxDialog.ObjectFilter = m_pGxObjectFilter
    m_pGxDialog.Title = "Select a Shapefile to Clean:"
    Set GetShapefile = pFc

    Exit Function

ErrorHandler:
Set GetShapefile = Nothing
End Function

Private Function CreateNewShapefile(pInFeatureClass As IFeatureClass) As IFeatureClass
Dim pClone As IClone
Dim pFeatureWorkspace As IFeatureWorkspace
Dim pFields As IFields
Dim pGxFile As IGxFile
Dim pNewFeatureClass As IFeatureClass
Dim pWorkspaceFactory As IWorkspaceFactory

On Error GoTo ErrorHandler

m_pGxDialog.Title = "Enter Scenario Name:"
m_pGxDialog.StartingLocation = "n:\FRM\FWIP_Scenarios\"
If m_pGxDialog.DoModalSave(0) Then
    Set pGxFile = m_pGxDialog.FinalLocation
Else
    Set CreateNewShapefile = Nothing
    Exit Function
End If

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pFeatureWorkspace = pWorkspaceFactory.OpenFromFile(pGxFile.Path, 0)
Set pClone = pInFeatureClass.Fields
Set pFields = pClone.Clone
Set pNewFeatureClass = pFeatureWorkspace.CreateFeatureClass(m_pGxDialog.Name, pFields, Nothing, Nothing, esriFTSimple, pInFeatureClass.ShapeFieldName, "")
Set CreateNewShapefile = pNewFeatureClass

Exit Function

ErrorHandler:
Set CreateNewShapefile = Nothing
End Function

Private Sub InsertFeature(pInsertFeatureCursor As IFeatureCursor, pInsertFeatureBuffer As IFeatureBuffer, pOrigFeature As IFeature, pGeometry As IGeometry)
Dim pFields As IFields
Dim pField As IField
Dim pPoint As IPoint
Dim FieldCount As Integer

'Copy the attributes of the orig feature the new feature
Set pFields = pOrigFeature.Fields
For FieldCount = 0 To pFields.FieldCount - 1  'skip OID and geometry
    Set pField = pFields.Field(FieldCount)
    If Not pField.Type = esriFieldTypeGeometry And Not pField.Type = esriFieldTypeOID _
        And pField.Editable Then
        pInsertFeatureBuffer.Value(FieldCount) = pOrigFeature.Value(FieldCount)
    End If
Next FieldCount

Set pInsertFeatureBuffer.Shape = pGeometry
pInsertFeatureCursor.InsertFeature pInsertFeatureBuffer

End Sub

Private Sub CreateIndexes(pInFeatureClass As IFeatureClass, pOutFeatureClass As IFeatureClass)
    Dim pClone As IClone
    Dim pOutIndexes As IIndexes
    Dim pIndex As IIndex
    Dim pNewIndex As IIndex
    Dim iIndexCount As Integer
    Dim pFields As IFields
    Set pClone = pInFeatureClass.Indexes
    Set pOutIndexes = pClone.Clone
    For iIndexCount = 0 To pOutIndexes.IndexCount - 1
        Set pNewIndex = pOutIndexes.Index(iIndexCount)
        Set pFields = pNewIndex.Fields
        pOutFeatureClass.AddIndex pNewIndex
    Next iIndexCount
End Sub

Private Function CreateNewGeometry(pFeatureClass As IFeatureClass) As IGeometry
    Select Case pFeatureClass.ShapeType
        Case esriGeometryPoint
            Set CreateNewGeometry = New Point
        Case esriGeometryMultipoint
            Set CreateNewGeometry = New Multipoint
        Case esriGeometryPolyline
            Set CreateNewGeometry = New Polyline
        Case esriGeometryPolygon
            Set CreateNewGeometry = New Polygon
    End Select
End Function

Private Sub CommandButton1_Click()
    Unload Me
End Sub

Private Sub Label13_Click()
End Sub

Private Sub Label8_Click()
End Sub

Private Sub TextBox1_Change()
End Sub

Private Sub TextBox12_Change()
End Sub
Private Sub TextBox13_Change()
End Sub
Private Sub TextBox2_Change()
End Sub
Private Sub TextBox6_Change()
End Sub
Private Sub TextBox7_Change()
End Sub
Private Sub TextBox8_Change()
End Sub
Private Sub UserForm_Initialize()
    TextBox1.Text = Format(totsaltload_R, "#,###")
    TextBox2.Text = errorsum
    TextBox4.Text = Format(totsaltload_W, "#,###")
    TextBox5.Text = Format(seeplength / 1000, "#,###")
    TextBox6.Text = Format(etarea_H / 10000, "#,###")
    TextBox7.Text = Int(modeledge_L / 1000)
    TextBox8.Text = Format((etarea_H + etarea_W + etarea_R) / vegarea * 100, "##.##")
    TextBox9.Text = Format(totsaltload_R + totsaltload_W, "#,###")
    TextBox10.Text = Format(etarea_R / 10000, "#,###")
    TextBox11.Text = Format(etarea_W / 10000, "#,###")
    TextBox12.Text = Format(vegarea / 10000, "#,###")
    TextBox13.Text = Format(seeplength / modeledge_L * 100, "#,###.#")
End Sub
## Appendix C: FRM GIS Fields and Visual Basic Code

### Table C1. FRM GIS field descriptions, typical values and units

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FRM parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRMID</td>
<td>The simplified vegetation communities were intersected with the FWIP divisions to create ~30,000 FRM vegetation polygons, each has a unique FRMID.</td>
<td>32541</td>
<td>-</td>
</tr>
<tr>
<td>DIVISIONID</td>
<td>The floodplain was divided into 3011 FWIP divisions that were ~250 m wide. The DIVISIONID is used to join the FRM table to the FWIP table to calculate FWIP risk</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>AREA</td>
<td>Floodplain vegetation polygon area.</td>
<td>2,247,473</td>
<td>m²</td>
</tr>
<tr>
<td>PERIMETER</td>
<td>Floodplain vegetation polygon perimeter.</td>
<td>16,111</td>
<td>m</td>
</tr>
<tr>
<td>HECTARES</td>
<td>Floodplain division area.</td>
<td>225</td>
<td>ha</td>
</tr>
<tr>
<td>FWIP</td>
<td>Indicates whether the division contains a wetland. A value of 0 indicates that the division does not contain a wetland, a value of 1 indicates that the division contains a permanent wetland, and a value of 11 that the division contains an ephemeral wetland.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>HIGH_RIVER</td>
<td>This field describes the FRM vegetation polygon position on the floodplain relative to the highland, wetland and river. A value of 1 indicates that the vegetation polygon is on the highland side of the wetland. A value of 2 indicates it is the wetland polygon. A value of 3 indicates that the vegetation polygon is on the river side of the wetland.</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>VEGCODE</td>
<td>One of 35 simplified vegetation codes (refer Table 9)</td>
<td>RGBB_W</td>
<td>-</td>
</tr>
<tr>
<td>TREEHEALTH</td>
<td>One of 6 health codes. A value of 'healthy', 'unhealthy' or 'dead' means the first tree species health rating was 'healthy', 'unhealthy' or 'dead', respectively. The word 'halophytes' was used when the vegetation code was either 'HALO_S' or 'PIGF_H' and there were no tree health ratings. The term 'not tree' was used when the vegetation code was either 'CHENO_S', 'FWIP', 'HERB', 'LIG_S' or 'WET' and there were no tree health ratings. The term 'not rec' was used when the vegetation code included a tree species, e.g. 'BB_W' but there was no tree health rating. These were mostly from the NSW data and areas mapped as willows.</td>
<td>healthy</td>
<td>unhealthy</td>
</tr>
<tr>
<td>TREENSX1</td>
<td>The corresponding DEH NSX code for TREESP1</td>
<td>U02218</td>
<td>–</td>
</tr>
<tr>
<td>TREENSX2</td>
<td>The corresponding DEH NSX code for TREESP2</td>
<td>C02245</td>
<td>–</td>
</tr>
<tr>
<td>TREENSX3</td>
<td>The corresponding DEH NSX code for TREESP3</td>
<td>C02245</td>
<td>–</td>
</tr>
<tr>
<td>HEALTH1</td>
<td>Health assessment for TREESP1. This is an average rating for that species across the entire polygon.</td>
<td>Healthy</td>
<td>–</td>
</tr>
<tr>
<td>HEALTH2</td>
<td>The health assessment for TREESP2. This is an average rating for that species across the entire polygon.</td>
<td>Healthy</td>
<td>–</td>
</tr>
<tr>
<td>HEALTH3</td>
<td>The health assessment for TREESP3. This is an average rating for that species across the entire polygon.</td>
<td>Unhealthy</td>
<td>–</td>
</tr>
</tbody>
</table>
### Table C1 continued.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>TREESP1</td>
<td>The Latin name of the first tree species present within the polygon. This may be the dominant or codominant tree species within the polygon and is related to the corresponding assessment found in the HEALTH1 item. If there is more than one health assessment done on the same tree species within the polygon, then this would be the most dominant health category.</td>
<td><em>Eucalyptus camaldulensis var. camaldulensis</em></td>
<td>–</td>
</tr>
<tr>
<td>TREESP2</td>
<td>The Latin name of the second tree species present in the polygon. This may be the sub-dominant or codominant tree species within the polygon and is related to the corresponding assessment found in the HEALTH2 item. If there has been more than one health assessment done on the same tree species within the polygon, then this would be the sub-dominant health category.</td>
<td><em>Eucalyptus largiflorens</em></td>
<td>–</td>
</tr>
<tr>
<td>TREESP3</td>
<td>The Latin name of the third tree species present in the polygon. This may be the sub-dominant or codominant tree species within the polygon and is related to the corresponding assessment found in the HEALTH3 item. If there has been more than one health assessment done on the same tree species within the polygon, then this would be the most sub-dominant health category.</td>
<td><em>Acacia stenophylla</em></td>
<td>–</td>
</tr>
<tr>
<td>MU_250_1</td>
<td>DEH Regional Floristic Description based on dominant overstorey for the first vegetation group in a mosaic (for use at 1:250,000 scale)</td>
<td>21</td>
<td>–</td>
</tr>
<tr>
<td>MU_250_2</td>
<td>DEH Regional Floristic Description based on dominant overstorey for the second vegetation group in a mosaic (for use at 1:250,000 scale)</td>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td>MU_250_3</td>
<td>DEH Regional Floristic Description based on dominant overstorey for the third vegetation group in a mosaic (for use at 1:250,000 scale)</td>
<td>26</td>
<td>–</td>
</tr>
<tr>
<td>REACH</td>
<td>Model reach where 0 = Mannum-Lock 1, 1 = Lock 1-2, 2 = Lock 2-3, 3 = Lock 3-4, 4 = Lock 4-5, 5 = Lock 5-6, 6 = Lock 6-model extent</td>
<td>6</td>
<td>–</td>
</tr>
<tr>
<td>High_Area</td>
<td>Vegetated division area between the highland and the wetland that is used to calculate the average rate of groundwater discharge as evapotranspiration through the floodplain between the highland and the wetland in the FWIP model.</td>
<td>238,669</td>
<td>m²</td>
</tr>
<tr>
<td>Wet_Area</td>
<td>Wetland division area that is used to calculate the average rate of groundwater movement into (‘ve) or out of (+’ve) the wetland in the FWIP model.</td>
<td>2,071,245</td>
<td>m²</td>
</tr>
<tr>
<td>River_Area</td>
<td>Vegetated division area between the wetland and the river that is used to calculate the average rate of groundwater discharge as evapotranspiration through the floodplain between the wetland and the river in the FWIP model.</td>
<td>2,008,804</td>
<td>m²</td>
</tr>
<tr>
<td>RIVERHEIGH</td>
<td>Area weighted elevation of the floodplain surface calculated using the FIM rounded to the nearest cm.</td>
<td>105</td>
<td>cm</td>
</tr>
<tr>
<td>RIVERFLOW</td>
<td>Area weighted flow to inundate the vegetation polygon calculated using the FIM rounded to the nearest 1,000 ML d⁻¹.</td>
<td>57000</td>
<td>ML d⁻¹</td>
</tr>
</tbody>
</table>
### Table C1 continued.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDGETOVEG</td>
<td>Distance of the centre of the vegetation polygon from the centre of the highland edge of the FWIP division.</td>
<td>42.7465</td>
<td>m</td>
</tr>
<tr>
<td>EDGETOWET</td>
<td>Distance of the centre of the wetland polygon from the centre of the highland edge of the FWIP division. This is equal to the EDGETOVEG value for all wetland polygons.</td>
<td>233.6563</td>
<td>m</td>
</tr>
<tr>
<td>RIV_ENT</td>
<td>Height of the river and anabranch creeks above sea level at entitlement flows (5,000 ML d⁻¹) based on the elevation of the closest river or creek kilometre marker derived from backwater curves, groundwater models and measured spot creek heights.</td>
<td>105</td>
<td>cm</td>
</tr>
<tr>
<td>GW_depth</td>
<td>Area weighted river level below the floodplain surface calculated using the FIM and the RIV_ENT fields.</td>
<td>325</td>
<td>cm</td>
</tr>
</tbody>
</table>

**FWIP salinisation risk parameters**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET_MM_D</td>
<td>The proportion of highland, wetland or river portions of the floodplain through which groundwater is discharged. It is calculated from the XCRIT_H, XCRIT_R, XW, L and ZSTAR fields. It ranges from zero, where there is no groundwater discharge, to one where the water table is within the vegetation rooting depth across that entire part of the floodplain.</td>
<td>0.5</td>
<td>–</td>
</tr>
<tr>
<td>ETrisk</td>
<td>Denotes whether the FWIP model predicts salinisation risk for that part of the floodplain. A value of zero denotes no groundwater discharge; a value of one indicates that groundwater discharge occurs in that part of the floodplain.</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Qs</td>
<td>The flux of groundwater discharged as seepage for the division calculated from the Qs and EDGE_L fields in the FWIP table.</td>
<td>0</td>
<td>m³ d⁻¹</td>
</tr>
</tbody>
</table>

**Flow input parameters**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WeirPoolRaising</td>
<td>Indicates whether the vegetation polygon falls within flooded area for the specified weir pool scenario. A value of zero denotes that the vegetation polygon is outside of the weir pool scenario.</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>FlowTable</td>
<td>Records the source of the flooding parameters, a choice between a 70,000 ML d⁻¹ flood and specified weir pool scenario.</td>
<td>70,000 ML/day flood</td>
<td>–</td>
</tr>
</tbody>
</table>
Table C1 continued.

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
<th>Typical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FRM salinisation risk classes</strong></td>
<td>Combines the FWIP and weir pool salinisation risk values based on the ETrisk and GW_depth fields, where high FWIP risk is when ETrisk = 1, low FWIP risk is when ETrisk = 0, high weir risk is when GW_depth ≤ 350 and low weir risk is when GW_depth &gt; 350.</td>
<td>Low FWIP high weir</td>
<td>–</td>
</tr>
<tr>
<td>FWIP_Weir_Risk</td>
<td>.operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HealthRiskFlooding</td>
<td>Combines the tree health, FWIP and weir pool salinisation risk values with the flooding potential based on the TREEHEALTH, ETrisk, GW_depth and RIVERFLOW or FLOODING fields, where 'high FWIP' is when ETrisk = 1, 'low FWIP' is when ETrisk = 0, 'high weir' is when GW_depth ≤ 200, 'med weir' is when 200 &lt; GW_depth ≤ 350, 'low weir' is when GW_depth &gt; 350, when the 70,000 ML d⁻¹ scenario is selected, 'yes flood' is when RIVERFLOW ≤ 70,000, 'no flood' is when RIVERFLOW &gt; 70,000, when the weir pool scenario is selected, 'yes flood' is when WeirPoolScenario = 1 and 'no flood' is when WeirPoolScenario = 0.</td>
<td>Healthy low FWIP high weir yes flood</td>
<td>–</td>
</tr>
</tbody>
</table>

**FRM Main Code Module**

```
Option Explicit

Dim pDoc As IMxDocument
Dim pLayer As ILayer
Dim pTable As IStandaloneTable
Dim pFeatureLayer As IFeatureLayer
Dim FRMFeatureClass, FRMFeatureClass2 As IFeatureClass
Dim FWIPTable, FWIPTable2, FlowTable, FlowTable2 As ITable
Dim FWIPTabletext, FlowTabletext, FRMFeatureClassText As String
Dim i As Integer
Dim FRMLayer As ILayer
Dim FWIPDataset, FlowDataset As IDataset
Dim pNFLayer As IFeatureLayer
Dim pMxDoc As IMxDocument
Dim fieldArray() As String
Dim pFields As IFields

Private m_pGxDialog As IGxDialog
Private m_pGxObjectFilter As IGxObjectFilter

Private Sub ComboBox1_Change()
End Sub

Private Sub ComboBox2_Change()
```
End Sub

Private Sub ComboBox3_Change()
End Sub

Public Sub UserForm_Initialize()

Dim pID As New UID
Dim pFeatureLayer As IFeatureLayer
Dim pDataset As IDataset
Dim pMap As IMap
Dim pMxDoc As IMxDocument
Dim LayerCount As Integer
Dim pUnknown As IUnknown
Dim pUnknownFL As IFeatureLayer
Dim pUnknownFC As IFeatureClass
Dim pFlowTable As ITable

Dim pStTabCol As IStandaloneTableCollection
Dim pStandaloneTable As IStandaloneTable
Dim ic As Integer

ComboBox1.Clear
ComboBox2.Clear
ComboBox3.Clear

Set pDoc = ThisDocument

' Add List of FWIP_scenario tables from map
Set pMap = pDoc.FocusMap
Set pStTabCol = pMap
ic = 0
For ic = 0 To pStTabCol.StandaloneTableCount - 1
    Set pStandaloneTable = pStTabCol.StandaloneTable(ic)
    ComboBox1.AddItem (pStandaloneTable.Name)
Next

' Add list of Flow_scenario tables from map
ComboBox2.AddItem ("70,000 ML/day flood")
ComboBox2.AddItem ("Weir pool raising")

' Add List of FRM_scenario shapefiles from map
For i = 0 To pDoc.FocusMap.LayerCount - 1
    Set pUnknown = pDoc.FocusMap.Layer(i)
    If TypeOf pUnknown Is IFeatureLayer Then 'A FeatureLayer
        Set pUnknownFL = pUnknown
        Set pUnknownFC = pUnknownFL.FeatureClass
        If pUnknownFC.ShapeType = esriGeometryPolygon Then
            Set pLayer = pUnknown
            ComboBox3.AddItem (pLayer.Name)
        End If
    End If
Public Sub CommandButton3_Click()

    Dim pEnumGxObject As IEnumGxObject
    Dim pGxDataset As IGxDataset
    Dim m_pGxDialog As IGxDialog
    Dim m_pGxObjectFilter As IGxObjectFilter

    ' Have the user select a table
    Set m_pGxDialog = New GxDialog
    Set m_pGxObjectFilter = New GxFilterTables
    Set m_pGxDialog.ObjectFilter = m_pGxObjectFilter
    m_pGxDialog.StartingLocation = "n:\FRM\"
    m_pGxDialog.Title = "Select a FWIP scenario:"

    If m_pGxDialog.DoModalOpen(0, pEnumGxObject) Then
        pEnumGxObject.Reset
        Set pGxDataset = pEnumGxObject.Next
        End If
    Set FWIPDataset = pGxDataset.Dataset

    ComboBox1.AddItem (FWIPDataset.Name)
    ComboBox1.Value = FWIPDataset.Name

    ' Find the FWIP file on disk and add to ArcMap
    Dim pFact As IWorkspaceFactory
    Dim pWorkspace As IWorkspace
    Dim pFeatws As IFeatureWorkspace
    Dim pTable As ITable

    Set pFact = New ShapefileWorkspaceFactory
    Set pWorkspace = FWIPDataset.Workspace
    Set pFeatws = pWorkspace
    Set pTable = pFeatws.OpenTable(FWIPDataset.Name)

    Dim pDoc As IMxDocument
    Dim pMap As IMap

    Set pDoc = ThisDocument
    Set pMap = pDoc.FocusMap

    ' Create a new standalone table and add it to the collection of the focus map
    Dim pStTab As IStandaloneTable
    Set pStTab = New StandaloneTable
    Set pStTab.Table = pTable

End Sub
Dim pStTabColl As IStandaloneTableCollection
Set pStTabColl = pMap
pStTabColl.AddStandaloneTable pStTab

' Refresh the TOC
pDoc.UpdateContents
End Sub

' Load the FRM scenario from file

Public Sub CommandButton5_Click()

    Dim pEnumGxObject As IEnumGxObject
    Dim pGxDataset As IGxDataset
    Dim m_pGxDialog As IGxDialog
    Dim m_pGxObjectFilter As IGxObjectFilter

    'Have the user select a shapefile
    Set m_pGxDialog = New GxDialog
    Set m_pGxObjectFilter = New GxFilterFeatureClasses
    Set m_pGxDialog.ObjectFilter = m_pGxObjectFilter
    m_pGxDialog.StartingLocation = "n:\FRM\FRM_Scenarios\"
    m_pGxDialog.Title = "Select an FRM scenario:"

    If m_pGxDialog.DoModalOpen(0, pEnumGxObject) Then
        pEnumGxObject.Reset
        Set pGxDataset = pEnumGxObject.Next
        Set FRMFeatureClass2 = pGxDataset.Dataset
    Else
        'need to deal with cancel button
        End If

    ComboBox3.AddItem (FRMFeatureClass2.AliasName)
    ComboBox3.Value = FRMFeatureClass2.AliasName

    ' Add the new scenario to the Map

    Dim pWorkspaceFactory As IWorkspaceFactory
    Dim pFeatureWorkspace As IFeatureWorkspace
    Dim pMxDocument As IMxDocument
    Dim pMap As IMap

    Set pFeatureLayer = New FeatureLayer
    Set pFeatureLayer.FeatureClass = FRMFeatureClass2
    pFeatureLayer.Name = FRMFeatureClass2.AliasName
    'Add the FeatureLayer to the focus map
    Set pMxDocument = Application.Document
    Set pMap = pMxDocument.FocusMap
    pMap.AddLayer pFeatureLayer

End Sub

'Cancel button
The Floodplain Risk Methodology (FRM)

Private Sub CommandButton1_Click()
    Unload Me
End Sub

'------------------------------------------------------------------
'
' Calculate Risk
'
'------------------------------------------------------------------

Private Sub CommandButton2_Click()

    Dim pDoc As IMxDocument
    Set pDoc = ThisDocument

    Dim FWIPTable As ITable
    Dim FWIPTabletext As String
    Dim FWIPTableName As IName
    Dim FWIPTableDataset As IDataset

    Dim FRMLayer As IFeatureLayer
    Dim FRMFeatureClass As IFeatureClass
    Dim FRMTable As ITable
    Dim FRMFeatureClasstext As String

    Dim FlowTable As ITable
    Dim FlowTabletext As String
    Dim FlowTableName As IName
    Dim FlowTableDataset As IDataset

    FWIPTabletext = ComboBox1.Value
    FlowTabletext = ComboBox2.Value
    FRMFeatureClasstext = ComboBox3.Value

    'Get FWIP scenario file
    i = 0
    Dim pStTabCol As IStandaloneTableCollection
    Dim pMap As IMap
    Set pMap = pDoc.FocusMap
    Set pStTabCol = pMap
    Dim pStandaloneTable As IStandaloneTable
    Dim SAFWIPTable As IStandaloneTable
    Dim pDataset2 As IDataset
    Dim pTable As ITable

    For i = 0 To pStTabCol.StandaloneTableCount - 1
        Set pStandaloneTable = pStTabCol.StandaloneTable(i)
        If UCase(pStandaloneTable.Name) = UCase(FWIPTabletext) Then
            Set SAFWIPTable = pStandaloneTable
        End If
    Next

    Set FWIPTable = SAFWIPTable.Table

    'Get FRM file
For i = 0 To pDoc.FocusMap.LayerCount - 1
    If TypeOf pDoc.FocusMap.Layer(i) Is IFeatureLayer Then
        If UCase(pDoc.FocusMap.Layer(i).Name) = UCase(FRMFeatureClass) Then
            Set FRMLayer = pDoc.FocusMap.Layer(i)
            Exit For
        End If
    End If
Next

Set FRMFeatureClass = FRMLayer.FeatureClass
Set FRMTable = FRMLayer

    FWIP table = FWIPTable
    Flow table = FlowTable
    FRM table = FRMTable

'------------------------------------------------------------------
' Create virtual relate between FRMLayer and FWIPTable using the "DivisionID" field
'------------------------------------------------------------------
Dim pMemRelFact As IMemoryRelationshipClassFactory
Dim pRelClass As IRelationshipClass
Dim pDispRC As IDisplayRelationshipClass
Dim strJnField As String
Dim divisionID As Integer
Dim Qs, high_mm_d, wet_mm_d, river_mm_d, nonveg_mm_d As Double
Dim zstar, xwstar As Double
Dim Flow As Long
Dim FF As Double
Dim pStTable As IStandaloneTable
Dim pDispTable2 As IDisplayTable
Dim pTTable As ITable
Dim FRMJoinLayer As ILayer
Dim FRMJoinTable As ITable
Set pDispTable2 = SAFWIPTable
Set pTTable = pDispTable2.DisplayTable
Set pMemRelFact = New MemoryRelationshipClassFactory
strJnField = "DivisionID"
Set pRelClass = pMemRelFact.Open("FWIPFRMRelate", pTTable, strJnField, FRMFeatureClass, strJnField, "forward", "backward", esriRelCardinalityManyToMany)

' use Relate to perform a join
Set pDispRC = FRMLayer
pDispRC.DisplayRelationshipClass pRelClass, esriLeftOuterJoin
Set FRMJoinLayer = pDispRC
Set FRMJoinTable = FRMJoinLayer

'Turn on the editor
pID = "esriCore.Editor"
Set pEditor = Application.FindExtensionByCLSID(pID)
Dim pDataset As IDataset
Set pDataset = FRMLayer.FeatureClass

' Check if in editing mode already
If Not pEditor.EditState = esriStateEditing Then
    MsgBox (pEditor.EditState)
pEditor.StartEditing pDataset.Workspace
End If

'------------------------------------------------------------------
'   Calculate the ROWS of the joined FRM - FWIP display table
'------------------------------------------------------------------
'
Dim pCur As ICursor
Dim pRow As IRow
Dim pFCur As IFeatureCursor
Dim pFeat As IFeature
Dim pCountRows As Long
'
Set pCur = FRMJoinTable.Search(Nothing, False)
Set pRow = pCur.NextRow
Set pFCur = FRMLayer.Search(Nothing, False)
Set pFeat = pFCur.NextFeature

pCountRows = FRMJoinTable.RowCount(Nothing)
'
' Set up the progress window
Dim pProgressDlgFact As IProgressDialogFactory
Dim pProgressDialog As IProgressDialog2
Dim pStepProgressor As IStepProgressor
Dim pTopoOperator As ITopologicalOperator2
Dim pTrackCancel As ITrackCancel
Dim lFeatureCount As Long
Dim lTotalFeatureCount As Long
Dim lEmptyFeatureCount As Long
Dim bContinue As Boolean

Exit if featureclass has no shapes
lTotalFeatureCount = FRMFeatureClass.FeatureCount(Nothing)
If lTotalFeatureCount = 0 Then
    MsgBox "No features found in shapefile. Exiting"
    Exit Sub
End If

'Exit if featureclass has no shapes
lTotalFeatureCount = FRMFeatureClass.FeatureCount(Nothing)
If lTotalFeatureCount = 0 Then
    MsgBox "No features found in shapefile. Exiting"
    Exit Sub
End If

' Show a progress dialog while we cycle through the features
Set pTrackCancel = New CancelTracker
Set pProgressDlgFact = New ProgressDialogFactory
Set pProgressDialog = pProgressDlgFact.Create(pTrackCancel, 0)
pProgressDialog.CancelEnabled = True
pProgressDialog.Title = "Calculating Floodplain Risk Categories"
pProgressDialog.Animation = esriProgressGlobe
bContinue = True
'Set the properties of the Step Progressor
Set pStepProgressor = pProgressDialog
pStepProgressor.MinRange = 0
pStepProgressor.MaxRange = lTotalFeatureCount
pStepProgressor.StepValue = 1

For i = 0 To pCountRows - 1
  'For i = 0 To 100
  
  'Update progress dialog
  lFeatureCount = lFeatureCount + 1
  pStepProgressor.Message = lFeatureCount & " of " & lTotalFeatureCount & " polygons calculated"
  'Stop processing features if 'Cancel' button is selected
  bContinue = pTrackCancel.Continue
  pStepProgressor.Step

  divisionID = pRow.Value(46)
  high_mm_d = pRow.Value(92)
  wet_mm_d = pRow.Value(93)
  river_mm_d = pRow.Value(94)
  nonveg_mm_d = pRow.Value(95)
  zstar = 1# - pRow.Value(57) / pRow.Value(56)
  xwstar = pRow.Value(64) / pRow.Value(55)
  Qs = pRow.Value(54) * pRow.Value(71)
  pFeat.Value(32) = Qs

  ' Add the ET value from the FWIP table into the FRM table
  If pFeat.Value(26) = 1 Then 'highland part of division
    pFeat.Value(30) = high_mm_d
  ElseIf pFeat.Value(26) = 2 And wet_mm_d >= 0 Then 'wetland part of division and ET>0 is downward
    pFeat.Value(30) = 0
  ElseIf pFeat.Value(26) = 2 And wet_mm_d < 0 Then 'wetland part of division and ET<0 is upward
    pFeat.Value(30) = -1 * wet_mm_d
  ElseIf pFeat.Value(26) = 3 Then 'river part of division
    pFeat.Value(30) = river_mm_d
  End If

  'Calculate the ETRisk field
  If pFeat.Value(30) > 0 Then
    pFeat.Value(31) = 1
  Else
    pFeat.Value(31) = 0
  End If

  'Calculate the FWIP_Weir_Risk field

  If pFeat.Value(31) = 1 And pFeat.Value(37) > 350 Then
    pFeat.Value(41) = "High FWIP" & " low weir"
  ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) <= 350 Then
If pFeat.Value(37) > 200 Then
    pFeat.Value(41) = "High FWIP" & " med weir"
Else
    pFeat.Value(41) = "High FWIP" & " high weir"
End If

ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) > 350 Then
    pFeat.Value(41) = "High FWIP" & " med weir"
ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) <= 350 Then
    If pFeat.Value(37) > 200 Then
        pFeat.Value(41) = "High FWIP" & " high weir"
    Else
        pFeat.Value(41) = "High FWIP" & " high weir"
    End If
End If

'Calculate the HealthRiskFlooding field
If FlowTableText = "70,000 ML/day flood" Then
    If pFeat.Value(31) = 1 And pFeat.Value(37) > 350 And pFeat.Value(23) > 70000 Then
        pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " low weir " & "no flood"
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) > 350 And pFeat.Value(23) <= 70000 Then
        pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " low weir " & "yes flood"
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) <= 350 And pFeat.Value(23) > 70000 Then
        If pFeat.Value(37) > 200 Then
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " med weir " & "no flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " high weir " & "no flood"
        End If
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) <= 350 And pFeat.Value(23) <= 70000 Then
        If pFeat.Value(37) > 200 Then
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " med weir " & "yes flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " high weir " & "yes flood"
        End If
    ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) > 350 And pFeat.Value(23) > 70000 Then
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " low weir " & "no flood"
    ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) > 350 And pFeat.Value(23) <= 70000 Then
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " low weir " & "yes flood"
    ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) <= 350 And pFeat.Value(23) > 70000 Then
        If pFeat.Value(37) > 200 Then
            pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " med weir " & "no flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " high weir " & "no flood"
        End If
    End If
ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) <= 350 And pFeat.Value(23) <= 70000 Then
    If pFeat.Value(37) > 200 Then
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " med weir " & "yes flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " high weir " & "yes flood"
    End If
End If

ElseIf FlowTabletext = "Weir pool raising" Then
    If pFeat.Value(31) = 1 And pFeat.Value(37) > 350 And pFeat.Value(27) = 0 Then
        pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " low weir " & "no flood"
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) > 350 And pFeat.Value(27) = 1 Then
        pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " low weir " & "yes flood"
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) <= 350 And pFeat.Value(27) = 0 Then
        If pFeat.Value(37) > 200 Then
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " med weir " & "no flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " high weir " & "no flood"
        End If
    ElseIf pFeat.Value(31) = 1 And pFeat.Value(37) <= 350 And pFeat.Value(27) = 1 Then
        If pFeat.Value(37) > 200 Then
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " med weir " & "yes flood"
        Else
            pFeat.Value(42) = pFeat.Value(8) & " high FWIP" & " high weir " & "yes flood"
        End If
    End If

ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) > 350 And pFeat.Value(27) = 0 Then
    pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " med weir " & "no flood"
Else
    pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " high weir " & "no flood"
ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) > 350 And pFeat.Value(27) = 1 Then
    pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " low weir " & "yes flood"
ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) <= 350 And pFeat.Value(27) = 0 Then
    If pFeat.Value(37) > 200 Then
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " med weir " & "no flood"
    Else
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " high weir " & "no flood"
    End If
ElseIf pFeat.Value(31) = 0 And pFeat.Value(37) <= 350 And pFeat.Value(27) = 1 Then
    If pFeat.Value(37) > 200 Then
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " med weir " & "yes flood"
    Else
        pFeat.Value(42) = pFeat.Value(8) & " low FWIP" & " high weir " & "yes flood"
    End If
End If

'Record the FWIP table name
pFeat.Value(34) = FlowTabletext
pFeat.Value(35) = FWIPTabletext
pFeat.Store
Set pRow = pCur.NextRow
Set pFeat = pFCur.NextFeature

Next

pProgressDialog.HideDialog
pDoc.ActiveView.Refresh

' Make sure the selected layer is joined
Dim pDispTable As IDisplayTable
Set pDispTable = FRMLayer
Set pTable = pDispTable.DisplayTable
If Not TypeOf pTable Is IRelQueryTable Then
    MsgBox "The layer or table is not joined"
    Exit Sub
End If

Dim pRelQTab As IRelQueryTable
Set pRelQTab = pTable
Set pTable = pRelQTab.SourceTable

' Remove the Join from between the FRMLayer and FlowTable
Set pDispRC = FRMJoinTable

' If more than one table had been joined, replace the current join with the previous join
If TypeOf pTable Is IRelQueryTable Then
    Set pRelQTab = pTable
    pDispRC.DisplayRelationshipClass pRelQTab.RelationshipClass, esriLeftInnerJoin
Else
    pDispRC.DisplayRelationshipClass Nothing, esriLeftInnerJoin
End If

pProgressDialog.HideDialog
pDoc.ActiveView.Refresh
pEditor.StopEditing True

Unload Me
End Sub