Modelling River and Floodplain Interactions for Ecological Response

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Abstract. The study of "Environmental Flows" - selecting regulated flow regimes that support aspects of the biotic and abiotic environment - has received increasing attention in the Murray-Darling Basin during the 1990's. The Basin contains a large number of dams, weirs and levee banks which have changed the nature of instream and floodplain habitat by altering the time-varying depth of river channels and the frequency and duration of floodplain inundation. The ability to model water movement between the instream and floodplain is fundamental for assessing the quality of aquatic habitat for riverine biota, particularly floodplain vegetation and waterbirds. Precise hydraulic modelling of these relationships is difficult because of the lack of appropriately scaled information to describe floodplain topography and surface roughness, both of which vary in space and time. This paper describes a framework to allow simple modelling of average water depth and flood duration in floodplain environments using a partial water balance. Water bodies are defined as a one-dimensional storage representing the quantity of water in the storage per unit time. The storages are filled and drained by conceptual pipes that have a given discharge per unit time. Pipes have a limited capacity and a position along the storage vertical axis which determines the threshold when water is released along the pipe and in what quantity. Each storage has a decay (loss) term and a maximum capacity. Water that is passed to a storage which has reached its maximum capacity is discarded, which means that there is no attempt to balance the water over the whole system. This simplification allows the framework to be easily set up yet still model properties of interest. Water bodies are spatially mapped as arbitrarily-shaped polygons with an associated storage. Pipes are connected between storages to move water around the landscape. A storage may have many input and output pipes. For example, losses to groundwater and evapotranspiration may be represented using an output pipe that is not connected to another storage, or may be associated with the decay term. This approach allows mixed scale representations and incremental improvements without changing the underlying structure of the system. This framework is one component of an Environmental Flows Decision Support System being developed by CSIRO Land and Water, Environment Canada and the Murray-Darling Basin Commission [Young *et al.*, 1997]. The modelling of habitat suitability for waterbirds is used to illustrate the approach.

1. INTRODUCTION

The ability to model water movement between the instream and floodplain is fundamental for assessing the quality of aquatic habitat for riverine biota, particularly floodplain vegetation and waterbirds. Precise hydraulic modelling of these relationships is difficult because of the lack of appropriately scaled information to describe floodplain topography and surface roughness, both of which vary in space and time.

Previous modelling of river/floodplain interactions [Porter *et al.*, 1991] have either used one or two dimensional models, the latter requiring large amounts of data for calibration. These models have mainly been developed to assess the likely impact of levee banks and proposed developments for farming and irrigation. The situation described here is somewhat simpler in that no prediction of new developments is required. Additionally, the model must be able to be applied in areas where there is little historical information and can be easily extended when such information becomes available.

The biotic response to flow may often be simply modelled by knowing how long an ephemeral area (connected to a river during flood) has been inundated. Although precise hydraulic modelling would achieve this result, the data requirements are too intensive for most sites. Fortunately, there is often local knowledge about the behaviour of the wetland in general terms. For example, overbank discharge values will be commonly known from gauged data and historical records. Additionally, the amount of time required for the wetland to dry out will be known through a verbal history, photographs, physical scarring, or may be estimated using topology, climate data and recent observations.

A system that allows a simple definition of river behaviour, based upon local knowledge of historical flow events and a simple assessment of current topography, is a useful tool for building river and floodplain models of biotic response to various flow regimes.

2. THE WATER MOVEMENT MODEL

The water movement model is based around the concept of a storage unit. A storage unit holds water which has been delivered via conceptual pipes clocked by a certain time step. A storage may have one or more input pipes of this form. A storage loses water in two ways; via conceptual output pipes, which drain the storage in a linear fashion based on a threshold of the storage volume, and via an exponential decay term, which drains the storage at a rate determined by the current storage volume. The loss represented by this decay is discarded. A storage has a maximum capacity which cannot be exceeded. In the event that the input to a storage causes the storage volume to exceed this maximum, the excess is discarded and the storage volume is set to the capacity. Hence there is no attempt to achieve an overall water balance for the system. A simple example of the various components that make up a single storage are shown in Figure 1.

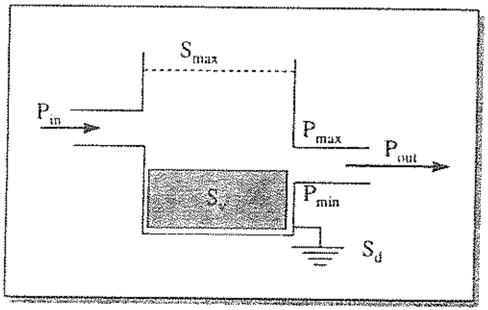

Figure 1. The Basic Storage Unit

The storage S is represented by a current storage volume, S_v, and a maximum storage capacity S_{max}. One or more input pipes, P_{in}, are used to fill S. The storage is drained in a nonlinear fashion using the decay factor S_d. Zero or more linear output pipes, P_{out}, may be associated with S. These output pipes are used to drain water from S if the volume of water S_v exceeds P_{min} for the pipe. The maximum carrying capacity for an output pipe is given by P_{max} - P_{min} . These output pipes may then be directed to other storage's in the system, or their output may be discarded.

2.1 Calculating Storage Behaviour for One Time Step

Based on Figure 1, the following algorithm determines the values for the output pipe and the new storage volume for a single time step. The input pipe, P_{in}, drives the system and is set at the beginning of the time step. The four steps involved in calculating the next state of the storage are as follows:

2.1.1. Add Input Pipe to the Storage Volume

$$S_v = \min(S_v + P_{in},\ S_{max}) \tag{1}$$

2.1.2. Calculate Output Pipe, P_{out}

$$P_{out} = \max(0,\ \min(P_{max} - P_{min},\ S_v - P_{min})) \tag{2}$$

2.1.3. Remove Output from the Storage Volume

$$S_v = S_v - P_{out} \tag{3}$$

2.1.4. Calculate the lose due to the decay term, S_d

$$S_v = S_v * \exp(S_d) \tag{4}$$

Note that setting $S_d = 0.0$ means that no exponential decay occurs for the system. Additionally, the model does not consider any time lag between water leaving one storage and travelling to another. Experience with this model will be required to determine whether a meaningful time lag should be included with the water movement.

2.2 Calculating the Storage Behaviour for Multiple Input and Output Pipes

The previous section described how to allocate the storage volume for a simple storage with one input and output pipe. The calculation of the new storage volume due to multiple input pipes is just an extension to equation (1), where there is a summation over all input pipes. The extension of multiple output pipes changes the way in which Equation (2) is interpreted. Basically, each output pipe is ordered based on the value of P_{max} for the pipe. Water is allocated to each output pipe in turn from the pipe with the greatest value of P_{max} through to the least value. It is assumed that no output pipes overlap. Each allocation of water to an output pipe adjusts the storage volume,S_v, based on Equation (3). Finally, irrespective of the number of input and output pipes, the final storage volume, S_v, is reduced using Equation (4).

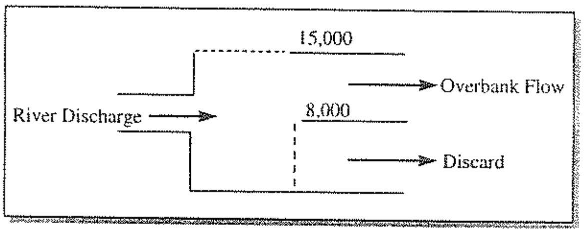

Figure 2. Representing a simple overbank flow

2.3 A Simple Example

Figure 2 shows a simple example representing the behaviour of a river which has an overbank event when the daily discharge is greater than 8,000 ML. Additionally, it is assumed that no more than 7,000 ML can pass out of the river each day. The important features to note with this setup are the discard output pipe, which essentially empties the storage each day, and the maximum storage capacity (S_{max}) of 15,000 ML. This maximum capacity ensures that no more than 7,000 ML per day is passed down the overbank flow output pipe.

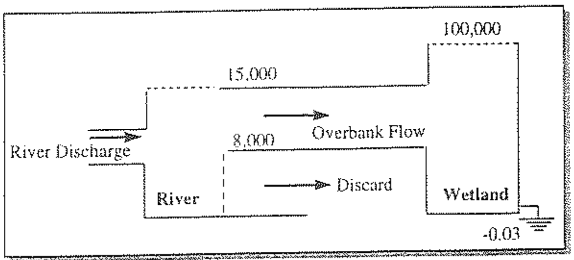

Figure 3. Combined River and Wetland

Connecting this river overbank flow pipe to a storage representing a small wetland is shown in Figure 3. Here a floodplain wetland is fed water when an overbank event occurs. This (imaginary) wetland has an approximate capacity of 100,000 ML, and empties in about 6 months upon filling. Note that the wetland has only one input pipe (from the river), and no output pipe. Losses for the wetland are represented using the nonlinear decay term. Although this is a very simple setup for the wetland, the modelled behaviour of the total water storage appears quite realistic, as shown in Figure 4. Here, historical daily flow data (shown as black columns representing ML/day discharge) is used to drive this imaginary wetland system. The decay term is set to -0.03.

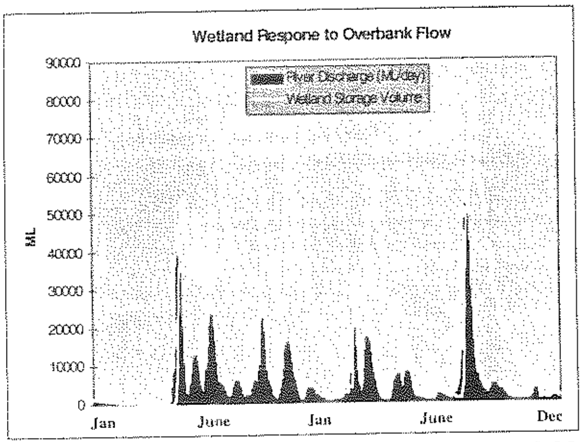

Figure 4. Wetland Response using Decay $S_d = -0.03$

The imaginary wetland system could also have been modelled using a linear output pipe, as shown in Figure 5. Here, an output pipe removes up to 1,200 ML per day from the storage. This output is discarded. Note that this setup will drain the wetland entirely. The response for the same two years of data is shown in Figure 6.

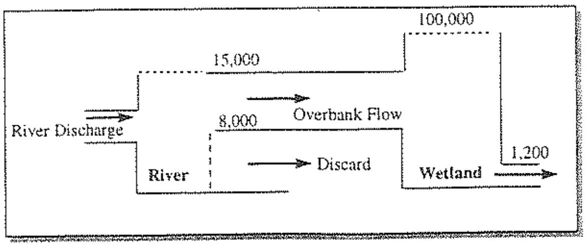

Figure 5. River and Wetland with Linear Output Pipe

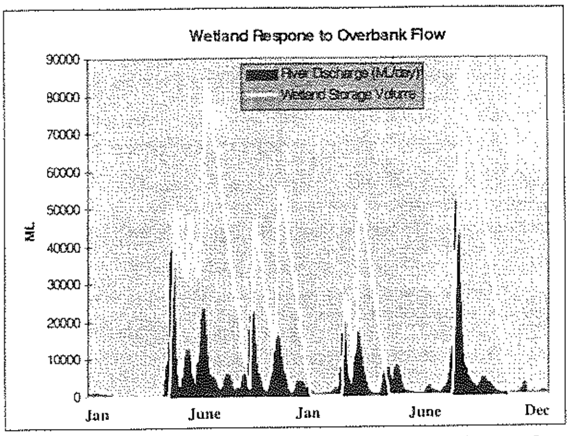

Figure 6. Linear Output Pipe of 1,200 ML per day

An example wetland setup that combines a decay factor and an output pipe is shown in Figures 7 and 8. Note that the output pipe capacity is 200 ML per day, and that the decay factor is -0.02. As can be seen from these examples, there are many ways to calibrate the system so that the behaviour conforms to certain basic properties such as the maximum capacity of the wetland and the drying time.

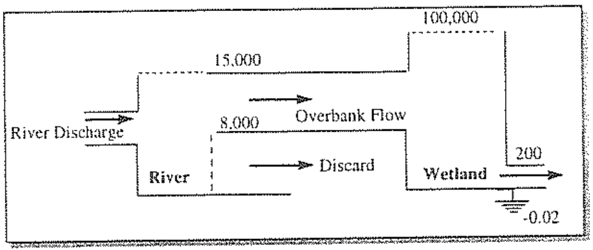

Figure 7. Output Pipe and Decay

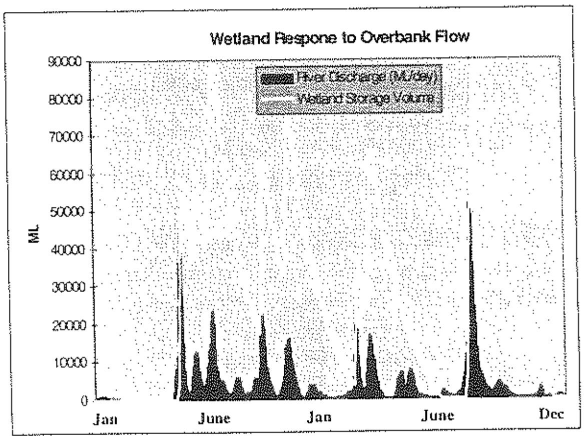

Figure 8. Output Pipe (200ML/day) and Decay $S_d = -0.02$

2.4 Modelling the Average Depth of a Storage

The average depth of a storage is determined by assuming that the storage itself is a homogeneous polygon of area A, and that the storage volume, S_v, is uniformly distributed through A. Hence, the average depth of a storage (using appropriate units) is given by:

$$\text{Average Depth of Water} = S_v \ / \ A \qquad (5)$$

Note that although this is very simple, the accuracy of individual sections of any modelled area may be improved by splitting the storage into multiple components. Each sub-storage may then be used to model a smaller spatial section and therefore allow more detail to be modelled when the information is available.

The ability to define any storage in more detail (by replacing its current definition by more than one storage) is analogous to creating a hierarchy of spatial scales, although there is no explicit restriction on the scale represented by any storage.

3. ENVIRONMENTAL FLOW MODELLING

Historically, most environmental flow modelling has been limited to instream environments. For large lowland rivers however, the floodplain is an equally important component of the riverine environment, both as habitat for a range of biota, and as a source of organic carbon to drive instream food-webs. The assessment of the environmental consequences of any flow regime for these rivers requires an assessment of the impacts of the regime on the floodplain environment. The water movement model proposed above, offers the ability to model in a simple manner the flooding regime of these floodplain environments. Arguably the most important aspect of the floodplain environment is the floodplain vegetation. However, in the Murray-Darling Basin floodplain vegetation provides the structural habitat for many migratory waterbird species. The breeding success of these birds is closely linked with flooding, and so serves as a useful indicator of the environmental consequences of a given flow regime.

The many ephemeral wetlands in the Murray-Darling Basin are important habitat areas for many such species of waterbird. As described by Scott [1997], "*When ephemeral wetlands dry up, the dead aquatic vegetation, fish and invertebrates form a rich organic substrate. In the dry period, grasses and other dryland vegetation start to grow in the basins. On reflooding, these rich organic substrates and the decaying flooded vegetation provide resources for rapidly developing populations of detritivores. This is quickly followed by the development of a complex wetland flora and a large invertebrate population. The abundance of food provides ideal conditions for breeding of many species*" of waterbird. A successful waterbird breeding event requires the following:

- **A Stimulus for Breeding**. The stimulus for breeding of many Australian waterbirds is appropriately timed flooding . The best responses are in spring following inundation of a previously dry wetland.
- **Lag Time before Breeding**. If a flood occurs in autumn or winter, waterbird breeding generally commences 3-6 months later. If the flood occurs in spring or early summer there is a shorter lag, in the order of 2-3 months.
- **Minimum Duration of Flooding**. Waterbirds in the orders *Pelecaniformes* and *Ciconiiformes* take about 3.5 months to build their nests, lay and incubate their eggs and fledge their young.

From the above description it is clear that to predict when an ephemeral wetland is suitable for waterbird breeding requires the modelling of overbank flows, wetland filling behaviour and duration of inundation. This example is used to demonstrate the water movement model.

Taking a conservative figure of 7-10 months as a desirable flood duration, and using the setup for a wetland as shown in Figure 7, a plot may be produced showing the periods during which suitable waterbird breeding habitat occurred at this site. It is assumed that a flood event commences when the wetland storage volume increases from 0. Note that since an output pipe is used to drain some of the imaginary wetland the storage volume is guaranteed to go to zero in a finite time if no water is added via the input pipes. Using this formulation the predicted periods when suitable breeding habitat existed could be determined, based on S_v, as in Figure 9.

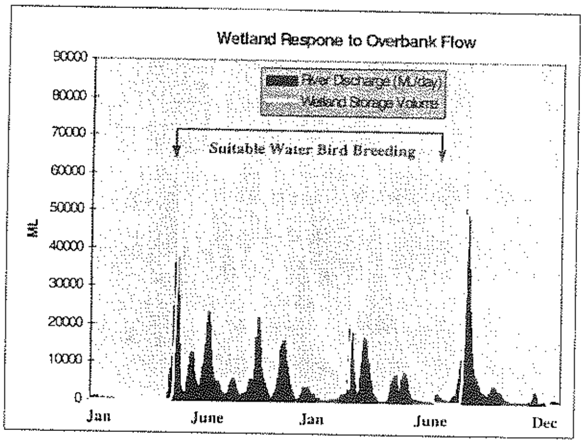

Figure 9. Predicting periods suitable for waterbird breeding

4. SUMMARY

Assessment of the environmental impacts of proposed flow management scenarios for lowland floodplain rivers requires information on the likely changes to the flooding regime. To be ecologically relevant this requires information on the frequency and duration of inundation of different floodplain environments. A simple water movement model has been proposed to allow such predictions to be made. This model will be used in the development of an Environmental Flows Decision Support System.

5. REFERENCES

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