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Modelling Floodplain Inundation under Natural and Regulated Flows in the Lower River Murray

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SUMMARY: A floodplain inundation model and the foundations of a Decision Support System for flood inundation from flow management have been developed using a Geographical Information System (GIS), remote sensing techniques and hydrological modelling for the lower portion of the River Murray. The area of the model covers the portion of the river from Lock 1 at Blanchetown in South Australia to the South Australian and New South Wales border. Flood inundation maps were developed from cloud free satellite imagery for a range of flows from 3,000 Ml/day (base level) to 102,000 Ml/day (1 in 13 year flood) measured at the border of South Australia and New South Wales. Area of inundation was determined by registering the images to map co-ordinates and classifying them to identify surface water and, through a process of interpolation, the area of inundation of intermediate flow events was modelled. The model operates by producing a series of river heights under any weir configuration and month for a given flow at the border which is now able to be generated into an area of inundation. This allows prediction of impacts on infrastructure, as well as, impacts on wetlands and floodplain vegetation from manipulation of the weirs. Flood extent can now be used as an input into the decision process for environmental flow management.

THE MAIN POINTS OF THIS PAPER

- Flow management requires the analysis of floodplain inundation and its effects of riparian vegetation.
- Satellite remote sensing provides an excellent tool for the identification of flood inundation.
- GIS can be used to store, analyse and model the spatial patterns of flood inundation and can be used to predict the extent of flooding from natural flows and from river regulation.

1. INTRODUCTION

Riverine ecosystems lend themselves to spatial analysis studies and visualisation techniques because they encompass three important temporally dynamic spatial dimensions and the physical and ecological processes taking place are complex. Many papers focus on the longitudinal (upstream and downstream) dimension and examine the ecological impacts of river regulation on native flora, fauna and the physical changes occurring in the littoral zone (Stanford *et.al.*, 1996). However long term modification of flow rates, frequency of flooding events and alteration to the timing of flows has now been identified to cause degradation beyond the littoral zone into both the lateral and vertical dimensions. This is particularly prevalent in the River Murray ecosystem where rising saline ground water has contributed to land degradation throughout the region and increased saline loading in the river. Furthermore the semi-arid nature of the Murray floodplain means that spatially and temporally flows are more extreme and less predictable (Walker and Thomas, 1993). Consequently this means that river regulation in the Murray has more severely impacted on the balance of physical and ecological processes which maintain this unique riverine environment. The following project draws from many disciplines and individuals using remote sensing techniques, spatial analysis techniques, hydrological modelling and computer programming to create the foundations of a Decision Support System, (DSS) for a flood inundation model of the River Murray. This paper will give details on the methods used to establish the GIS flood inundation model and will give a brief overview of the potential of the flooding component of the DSS for flow management.

1.1 Study Area

Satellite images and other data were obtained that capture the entire riparian and floodplain environments of the River Murray in South Australia, New South Wales and Victoria from Lock 10 at Wentworth to Lock 1 at Blanchetown. The flow management aspects of the model have concentrated on the lower part of this region that can be directly influenced by the South Australian Water Corporation in manipulating the flows (see figure 1).

Most of the basin is semi-arid or arid and the local geomorphology ranges from gorge sections below Overland corner, 2-3km wide and 30-40m deep to valleys 5-10km wide which is flanked by a broad floodplain (Walker and Thomas, 1993).

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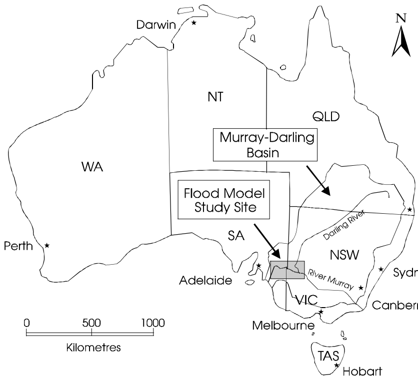

Figure 1. Study Area

2. FLOOD INUNDATION MAPPING

2.1 Production of flood inundation maps from satellite imagery

Previous modelling studies to determine the aerial extent of flooding have involved complex mathematical equations that extrapolate from point observations to large areas or have used very expensive elevation modelling from photogrammetry. Remote sensing is particularly useful to monitor flood extents because it provides basic data more cheaply and efficiently than ground based methods (Whitehouse, 1989). Remote sensing can also be considered the most accurate for delineation of flooding for the events that occurred at the time of the image, as opposed to, surface modelling which has to take into consideration artificial channels and restrictions to flow and the large changes in flooding that can occur over very small changes in river height.

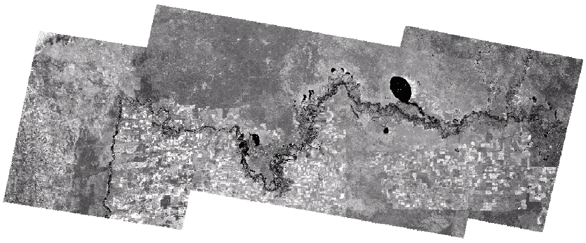

Figure 2: An example of four Landsat TM satellite scenes covering the study area from Lock 1 to Lock 10

Most of the information required on flood limits can be obtained from satellite images in the mid-infrared bands. Radiation in this region is almost completely absorbed by water and hence images show sharp contrast between the high reflectance in soil and vegetation on dry areas and the very low reflectance of water. Satellite imagery has been used for flood inundation mapping for many years (Walker *et.al.*, 1986). This project used the Landsat TM satellite to provide a good coverage of the area at a resolution of 30 metre by 30 metre cells ('pixels') on the ground (Figure 2) (see Overton 1997 for further details).

Water is detected by isolating the pixels within the image that are of very low reflectance values for the mid-infrared wavelengths. However other features, especially shadow, also have very low reflectance in this region. Detecting water from dark shadow is not possible using a single band image without complicated analysis or ground knowledge in the particular area. This problem is compounded by the slightly higher reflectance of turbid or shallow water giving reflectance values above dark shadow. The assessment on the cut-off value for determining surface water in a single band image is a judgement made by the analyst based on the histogram and visual image. Figure 3 shows the cut-off made for one of the images in the study area.

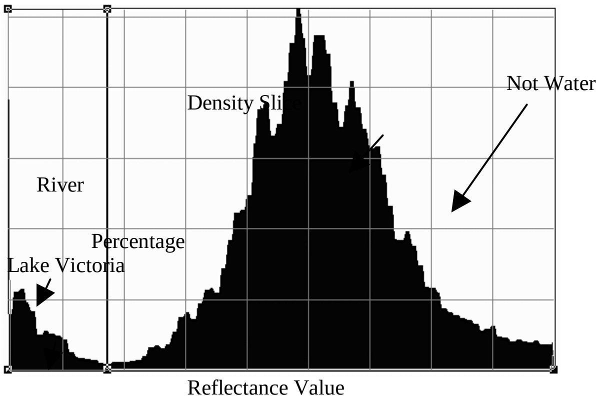

Figure 3: Histogram of a 102 GL/day flow with the central line indicates the point at which the reflectance value is split to indicate water or not water. Two low reflectance value peaks represent Lake Victoria (with deep water) and the River Murray (with shallow turbid water).

Despite the problems involved in individual pixels the method of density slicing a single mid-infrared band to detect surface water has been successfully used for years as described above. The images were chosen to correspond to a range of flow values as recorded at the Gauging Station 426200. The flows range from 3,460 Ml/day to 101,900 Ml/day with dates ranging from 27 October 1986 to 23 November 1996.

2.2 Registration and spatial accuracy of the imagery

The satellite images had to be registered to real world co-ordinates so that flood masks could be used within the GIS. Registration was performed using both map co-ordinates and digital data, as well as, image to image rectification once the first image was registered. Every effort was made to register the images to provide a useful dataset for modelling between images. Problems with overlaying images registered with this method must be considered as errors get compounded with additional overlays. This problem is of special concern in this study as individual pixels are being monitored over time for flooding or not flooding. Errors in the registration may cause a shadowing effect on the edges of the flood extent in some cases.

2.3 Flood map editing and coding of the flood masks.

In order to use the flood masks for hydrological management of the river it is important to understand the problems if taking a view of surface water and relating this to flood extent for a given flow. Some of the issues involve the identification of water that has no direct relationship to the river at the current flow. Water may not be connected to the river in the image in question but may be a remnant from a previously larger flow.

Water that occurred in the image due to rainfall or irrigation, are also not related to the river system. These areas needed to be removed in order to determine the exact extent of flooding that will occur at a particular flow. The process involved identifying the 1956 flood boundary and the relationship between increasing flow images. It was necessary to not only check the next higher flood image but all higher flow images to ensure that flood anomalies weren't missed and it was critical to look at images that represent a rise or peak in the hydrograph. This will be an ongoing process of editing the flood masks as new information becomes available from satellite imagery, aerial photography and ground recordings. Satellite imagery does not detect every pixel of water within the scene as some areas are covered by vegetation or have high turbidity or shallow depth. For this reason the areas that lie within the river channel itself and areas classified as permanent wetlands by Pressey, R.L. (1986) were assigned a unique code

To deal with the problems described above Arc/Info's raster based modelling package 'GRID' was used. A query was performed which assign codes to all the pixels in each image to represent the type of water as discussed above.

2.4 Interpolation of flood masks

The acquisition of satellite images at different flow rates is limited by the historical flow rates at the border, the cost and availability of the imagery for the study area and the timing of the imagery, i.e. whether the imagery is taken on a rising or lowering river or a cloud free day. Interpolation of discrete flow intervals was performed to produce finer intervals of flooding extents. Within the images, contiguous regions of constant flow values were separated from their surroundings. These regions were then used to obtain the interpolation points. Regions having the minimum flow value or representing land that did not flood at the largest flow were not included. Control points were chosen as pixels lying on the boundary of flooding regions.

Given a set of control points which are assumed to have flooded at the corresponding level of flow, the problem is to interpolate these points to obtain the flow at all other pixels in the image. There was an infinite number of ways to perform this interpolation. The true situation is defined by the local topography of the area which is not known, however, the flow level at which a given point becomes flooded is closely related to the height of the landscape at that point. Therefore interpolation of the flow level is similar to the problem of interpolating the landscape height at each point.

Interpolation of spatial data is a common problem in geographical realms. Although the values at points other than the control points are not known, the earth's surface generally varies in a spatially correlated fashion. Kriging is a popular interpolation method which seeks to obtain the best linear unbiased estimate of the data at interpolated points. The kriging stage of the project was done using the Matlab *Spatial and Geometrical Analysis Toolbox* (SaGA) (see Overton 1998 for methodology).

3. GIS MODELLING

3.1 Smoothing of raster data by using the majority filter

Filtering is a technique used to enhance the quality of digital imagery by changing the values of cells in a raster images and can be used to ease the computation burden of raster to vector conversion by removing isolated pixels (Trotter, 1991). Filtering uses neighbouring cells to determine the value of the cell in question and can sharpen or smooth images to emphasise features or detract from anomalies.

To remove anomalies in the interpolated flood masks, such as higher or lower value pixels in the middle of lakes, the majority filter available in ArcView's Spatial Analyst was used by writing an Avenue programme. This filter replaces the value of each pixel with the value of the eight nearest neighbours if there is a clear majority of neighbouring cells with a different value than the cell (see Wilkinson, 1996, for an overview on the generalisation process). This method eliminated isolated cells with a higher and lower flow found in lakes and preserved river and lake boundaries. Figure 4 shows an example of the original masked data before and data after smoothing.

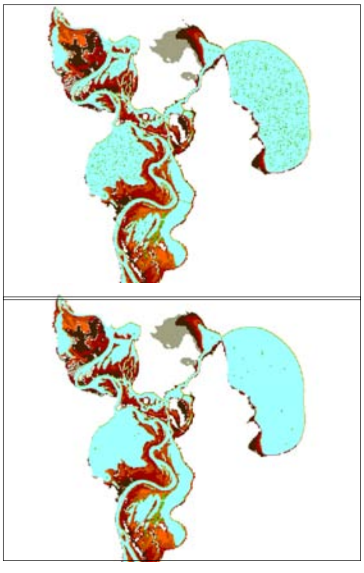

Figure 4: An example of the raster images before and after smoothing.

3.2 Converting the smoothed data to vector format

At this stage of the processing the imagery was still in raster format, (pixel based data). The raster data was converted to vector data (area or shape based data) to reduce the data redundancy and allow for easy retrieval, updating and generalisation of graphics and attributes which are especially important if equations are to be used to generate models. The smoothed data was converted to vector format in Arc/Info with the gridpoly command. Figure 5 shows an example of the smoothed raster format and the same area after the data set has been converted to vector.

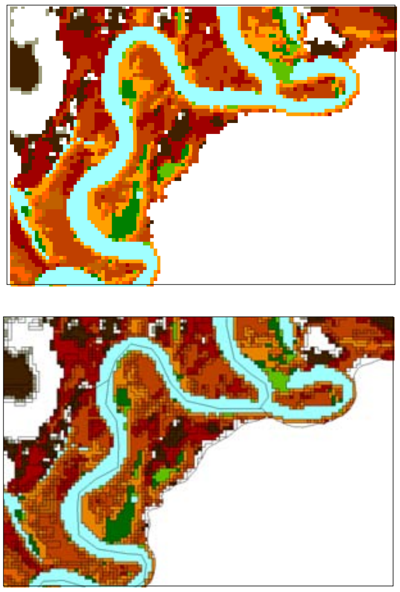

Figure 5: An example of the data in raster and vector format for an area near Bookpurnong, South Australia between Lock 5 and 6.

4. HYDROLOGICAL MODELLING

4.1 Flood Inundation Response Units

River heights at selected kilometre markers, derived from backwater curves, needed to be assigned to areas along the floodplain. Clearly river heights near the source of flow would not bear much of a relationship to areas of the floodplain closer to the mouth. Homogenous areas, or areas that responded to a particular point in the river of floodplain inundation were identified using flood behaviour and river morphology as a guide. Figure 6 shows the map layer created for the regions identified as Flood Inundation Response Units (FIRU).

4.2 Assigning a FIRU region to a trigger

In order to determine which areas would be flooded from which triggers, FIRUs were assigned to the closest trigger or the trigger that was assumed would most likely cause that area to flood. Figure 7 shows the flow rates as represented by the different images and the river heights along the river. There is very little difference between 2km intervals which implies that there is probably an error margin of 1 or 2 triggers in the assignment of a FIRU to a trigger. A look up table was created with the fields trigger and FIRU. This table was then joined to the final vector coverage of each Lock reach. Each polygon in the vector data set for a particular reach now contained attributes for Reach, FIRU, Flow and Trigger. Figure 6 shows an example of triggers that were selected for FIRU between Lock 3 and 4. Each FIRU now contained areas that flood at a particular flow or Unique Ecological Flood habitats, hereafter referred to as EFH.

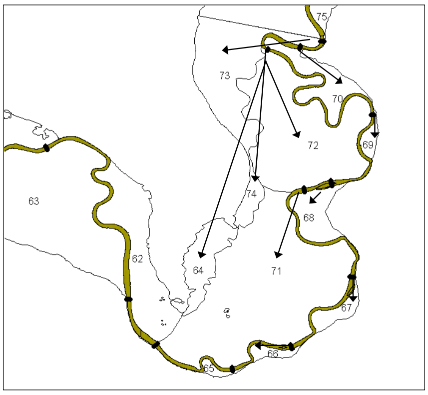

Figure 6: Trigger assignments to FIRU Regions for an area near Loxton, South Australia

4.3 Hydrological inputs to the model

Different flow rates at the border produce certain river elevations along the river. It is the local river height at kilometres along the river that determines whether the river will break the banks and flood an adjacent area. To progress with the analysis for each flow rate at the border a river height needed to be generated for kilometres along the river.

Actual recorded data of river height at certain kilometres from the mouth of the river and flow at the gauging station during the flooding events were obtained from SA Water. However a lack of sufficient points to generate a relationship meant that the 1991 backwater curves were also used. These were a series of water surface elevation curves between Locks for a steady uniform flow computed by a program MURLEV. This was a by-product of the hydraulic model development for the River Murray flow and Salt Transport Computer model (Water Studies, 1992). Figure 7 shows the flow attenuation curves derived from these methods for a section of the river from the border to Lock 2. The flow rate of 3 gigalitres is weir pool level.

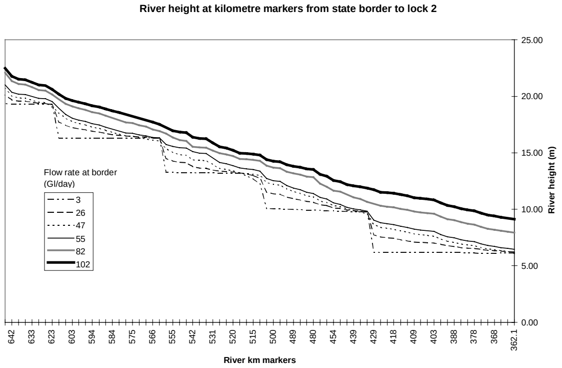

Figure 7: River levels for kilometres of the river from Lock 2 to the SA/NSW border for different flows.

4.4 The river height under any weir configuration and flow at the border

The backwater curves are known to be historically correct and accurate for the way the weir pools are operated to normal pool level. However they cannot be used as a basis for predictions under various weir configurations. Modelled backwater curves were considered to be a viable option.

Using Excel river level and discharge relationships for each Lock reach were established. The hydraulic data used to establish these relationships was derived from a peripheral model of the River Murray Flood Model called ‘BWAT’. ‘Bwat-nlr’ is used to estimate water level and storage along Lock pools under steady, non uniform flow conditions.

The model operates by estimating the stage discharge matrices used to route the inflow hydrograph down a river. For a nominated water level and discharge at the Lock the backwater model defines the upstream water levels to the next Lock. In this way relationships can be derived between the water levels at the downstream and upstream ends of a river segment and discharge. Figure 8 shows the backwater curve for Lock pool 3 at a level of 5 centimetres above normal pool level.

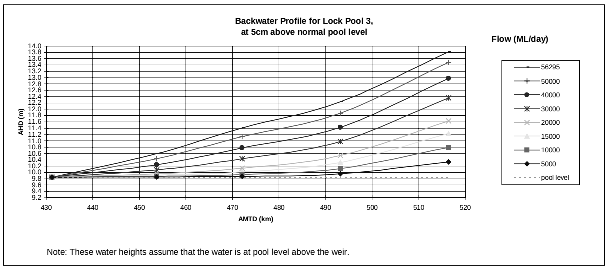

Figure 8: Example of a back water profile for Lock 2

4.5 The difference in flow and consequently river height due to seasonality

In summer a flow rate at the border will be reduced downstream of the flow source as more water is evaporated, extracted and less is replaced by rainfall. Curves were generated which show the attenuation of flow at each Lock for a given month. Figure 9 shows the change in flow rate to each of the Locks given a particular month.

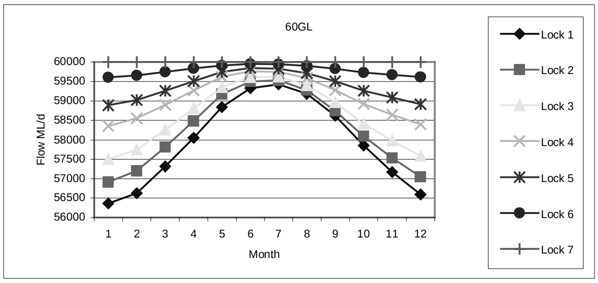

Figure 9: Example of seasonal attenuation curves.

5. DSS DEVELOPMENT

5.1 Coding the GIS for height

The height of the river at kilometre markers now had to be related to the management areas, the EFHs derived from the original flow values and the interpolation process. Originally flow values from the satellite images were regressed against the range of river heights for each trigger. This produced a spread of data points across the range of actual flow values. However, because area inundated is extremely sensitive to slight alterations in river height it was decided that a relationship between river height and area of flood inundation should be used in each FIRU. This relationship has the potential to be improved with further image acquisition and statistical analysis. It must be remembered that the model will always be limited to the spatial resolution at which it was acquired which in this instance is 30 metres regardless of the number of images used. If a change in the height of the river results in less than a 30 metre area change the area of inundation will not increase because it is still within the pixel of the lower flow value. The resultant area inundated to river height curves, (figure 10), show the relationship of the river height to the local topography of the floodplain.

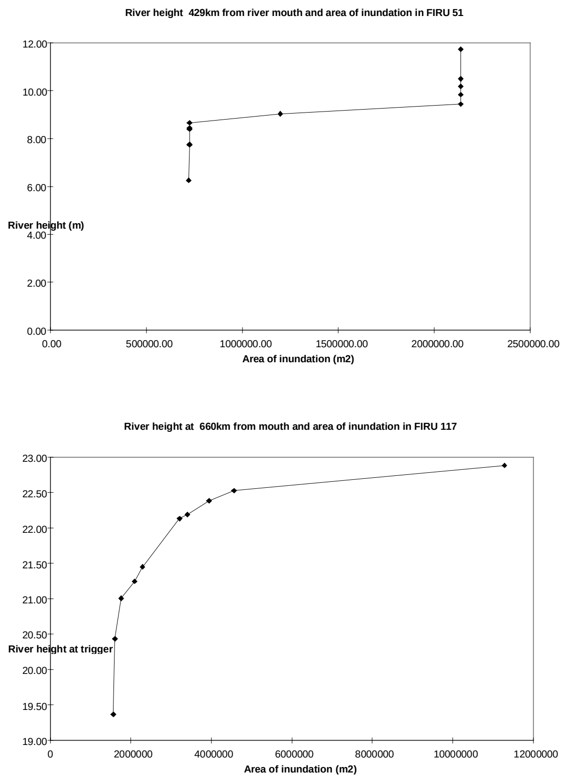

Figure 10: a) Lock 2 to 3; b) Lock 6 to 7

Figure 10a shows the relationship between river height and area inundated in a trench between Lock 2 and 3. The height of the river continues to increase without breaking the banks until it reaches approximately 8 and a half metres. As the water spans onto the floodplain there is a gradual increase until the river level rises to hit the outer trench. Figure 10b shows a typical floodplain area between Lock 6 and 7. Here the river height increases until breaking the banks and continues to increase as it fills up billabongs and then gradually tapers outs as the water spreads over the floodplain. These curves were used to code the flood masks with a river height which would cause the EFH to be inundated. An Avenue script was used to assign the height of the river to the EFH for all FIRUs using the FIRU trigger as the point that would cause this EFH to flood. A dialogue screen in ArcView was then designed with input fields to ask the user the values for the flow at the border. Avenue language was then used to perform a query which selects all the river height codings in the map layer where the flow is less than or equal to chosen flow. Figure 11 shows an example of the GIS flood inundation model.

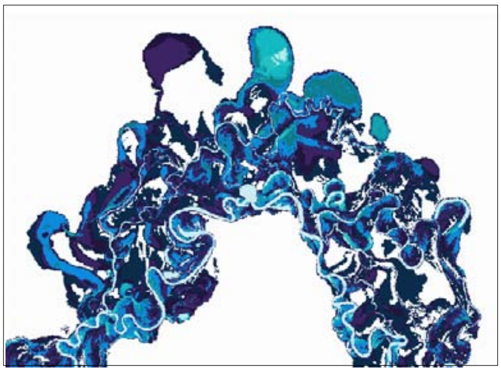

Figure 11: Example output of the GIS model showing one of the areas around Lock 6 at Chowilla with a range of floods with increasing flow from light to dark.

5.2 Building the Decision Support System for flow manipulation to flood extent

The initial stages of the project provided us with ecological flow management units and the height of the river at a particular trigger which would cause these areas to flood. The hydrological modelling parameters allow the simulation of a flow from the border under different weir configurations and months of the year, with the GIS providing the spatial view and a map of the area inundated. The inputs to the DSS are the flow at the border, the weir configurations of all 6 weirs and the month of year. The outputs of the model will be the river heights at each trigger kilometre and the area of inundation.

6. CONCLUSION

This paper has described the first phase of the development of a decision support system covering the prediction of the extent of floodplain inundation for a particular flow and operational regime. The second phase of development will be the impact of a particular regime on the floodplain and river users ranging from its environmental benefits to social impacts. Since the database created has a spatial component layers of useful data can be added such as riparian vegetation, aboriginal heritage areas, soil types, agricultural use, ground water problem areas. It is expected that the EFH will remain constant because the distribution of floodplain vegetation communities is strongly related to flooding frequency. With further development running the Decision Support System will not only give the user the flooding scenario but will also give the user the ability to query the areas of native vegetation effected or other features of interest that may be impacted if this type of flooding event is produced from the given weir configurations.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Overton, I.C. (1997). Satellite analysis of flood inundation for the River Murray Stage I Report. SA Water Report.

Overton, I.C. (1998). The development of a GIS for flood inundation, River Murray. Stage III Report. SA Water Report.

Pressey R.L, (1986). Wetlands of the River Murray below Lake Hume. Environmental Report 86/1. Murray-Darling Basin Commission: Canberra.

Stanford J.A, Ward J.V, Liss W.J, Frissell C.A, Williams R.N, Lichatowich J.A, Countant, C.C, (1996). A general protocol for restoration of regulated rivers, Regulated Rivers: Research & Management, 12, 391- 413

Trotter C, (1991). Remotely-sensed data as an information source for geographical information systems in natural resource management: a review, Int. J. of G.I.S., 5(2);225-239

Walker K.F and Thomas M.C, (1993). Environmental effects of flow regulation on the lower River Murray, Australia, Regulated Rivers: Research & Management, 8, 103-119

Walker R.D, Aubrey M.C and Fraser, S.J, (1986). Remote Sensing in Australia, Canbec Press Pty Ltd, Melbourne.

Water Studies, (1992). River Murray Flow Model, Vol. 3. User Manual. Dept. EWS June 1992. 92/12.

Whitehouse. G, (1989). 'Flood monitoring and Floodplain Studies'. In: 'Remote Sensing in Hydrological and Agrometeorological Applications'. Ed: de Vries, D. COSSA Publications, Canberra.

Wilkinson G.G, (1996). A review of the current issues in the integration of GIS and Remote Sensing data, International Journal of Geographic Information Systems, 10(1);85-101.