Executive Summary

The construction of a dam can drastically alter the flow regime and sediment load of the river downstream by altering flood peaks and durations, as well as by trapping large amounts of sediment. The imposed changes in the flow can lead to riverbed degradation directly downstream, as a result of very low sediment loads, as well as narrowing of river channels due to decreased transporting capacities further downstream. The increasing number and size of dams built during recent decades has drawn more attention to the impacts that dams can have, so much so that the World Commission on Dams (WCD, 2000a) has completed a worldwide study on dams. In South Africa there have also been some studies focusing on the impacts of river developments on a river system such as interbasin transfer schemes (Rowntree *et al.*, 2000). It has, however, become clear that there are still some issues to be addressed in order to gain a better understanding of the changes in the downstream river morphology that may occur as a result of dam developments

The overall aim of the project is to investigate the impacts of dam developments on the downstream river morphology, specifically:

- The assessment of the changes in the downstream river morphology as a result of different dam development scenarios.
- The development of methods for predicting the downstream river channel geometry for South African conditions.
- An investigation into the effects of clay and silt on the sediment transport behaviour of sediments.
- The development of a methodology to determine required flood magnitudes, duration and frequency downstream of a dam, to maintain (or restore) the river morphology as close as possible to the natural (or desired) conditions, based on fundamental hydraulic principles of sediment transport. This would provide tools with which environmental flow requirements, controlling the river morphology, can be analysed.

The following results have been obtained:

- The impacts of dams on the downstream river morphology depend to a large degree on the operation of the reservoir as well as the reservoir capacity in relation to the MAR,

since these two factors determine the magnitude, duration and frequency of all but the largest floods. Some examples of impacts are presented in **Table 1**:

Table 1 Impacts and causes

Impact	**Cause**
Riverbed degradation	Clear water spillage due to sediment trapped in reservoir
Coarsening of bed material	Clear water releases
Reduced sediment transport capacity	Attenuated flood peaks, coarser bed materials, flatter slopes
Riverbed aggradation	Reduced sediment transport capacity, tributary sediment supply
Increased riparian vegetation	Long periods of low or no flows
Narrowing of river channel	Increased riparian vegetation and smaller floods

- Regime equations describing the average width and depth of a river were developed, based on South African river data. The equations were verified with the aid of international river data, and compared to results obtained from semi-theoretical regime equations developed in the United States. The new regime equations compared favourably to these regime equations.

- The regime equations developed in **Chapter 3**, as well as other international regime equations are not suitable for predicting the channel geometry of rivers downstream of dams with highly unnatural release patterns, mainly as a result of the problems with the determination of the dominant discharge. Alternative regime width equations were developed.

- It has been found, through laboratory experiments, that as little as 7% clay and silt can affect the sediment transport behaviour of sand. When sediments contain more than 23% sand the erosion could be affected by armouring. At higher clay and silt contents (> 7%) almost no bedforms develop.

- A methodology was developed by which the critical conditions for mass erosion of cohesive sediments and cohesive – non-cohesive mixtures can be described in terms of the applied stream power at the bed. The applied stream power at the bed can be related to the percentage clay and silt in the bed material.

- Sediment transport equations in terms of the unit input stream power for cohesive and non-cohesive sediments, as well as mixtures of the two, were developed with data gained from laboratory experiments. The equations were successfully verified against independent flume data, as well as United States river data.

- One-dimensional modelling of the impact of existing and proposed new dams on two South African rivers and an estuary was carried out. By comparing sediment transport characteristics of pre-and post-dam scenarios, problem areas could be identified and mitigating procedures evaluated.

- Procedures were developed by which the impacts of dams on the downstream river morphology can be determined and mitigating measures developed.

- Environmental flood releases at medium and large dams, and sediment sluicing/flushing at small reservoirs (relative to the MAR), are required to limit the upstream and downstream impacts of a dam on the river and estuary morphology. By using observed and simulated discharge-sediment load relationships along a river for various development/operational scenarios, it is possible to design the peak discharge, frequency and duration of these environmental floods.

- Environmental flood releases will cause riverbed degradation close to the dam, but are required for channel maintenance of the greater part of the river further downstream to limit the overall impact of a dam.

The following recommendations can be made:

- Dams have dramatic impacts on the river morphology, far upstream and even further downstream. These impacts should not be underestimated in terms of ecological damage and costs, and should be investigated in great detail during planning, design and operation of the dam using suitable hydraulic techniques.

- It is recommended that the proposed procedures on the methodology to investigate the morphological impacts of dams be implemented in environmental flood requirement studies. The design of flood releases (or not) considering flood peak, duration, and frequency should be carried out using this methodology.

- Post-dam river width changes can be simulated by using regime equations developed in this study, but for more detailed investigations semi-two-dimensional or two-dimensional modelling should be carried out.

- River morphological simulations should be carried out over at least 15 years. Daily data are often not good enough due to the flood peak averaging.

- Flood flushing and managed flood releases from reservoirs should be implemented to take place simultaneously with a natural flood event for maximum efficiency.

- Generally the quality of the water released from reservoirs is very different than under natural conditions. In order to achieve the desired water quality, the design of multi-level outlet structures should be optimised to allow managed flood releases.

- Hydropower generation, causing large water level fluctuations, can seriously damage a river. Planned flood releases are difficult to implement in order not to interfere with the hydropower generation, so the hydropower releases have to be optimised to reduce geomorphological impacts, by limiting maximum release discharges and rate of change of discharges.

- A problem with determining IFR/EFR requirements is the difficulty in establishing the correct link between the abiotic drivers, e.g. hydrology and sediment transport, and the biotic components, such as the role of fine sediment transport. Detailed hydrodynamic and morphological simulations can yield more information, which can be significant for the biotic components.

- The proposed analysis procedures rely on long-term suspended sediment data taken in rivers to determine a sediment load – discharge relationship. Such data are available on most rivers in Africa and internationally, but are limited in South Africa. It is important that suspended sediment sampling is continued as soon as possible at most of the South African flow gauging stations.

- The natural river geomorphology is generally used as a reference condition against which to evaluate any future changes. At future planned dam sites monitoring of the river morphology should be carried out, such as repeat surveys, in order to establish the reference condition and any subsequent changes.

- The sediment transport theory of sand, gravel and even fine sediment is well established. However, the sediment transport of cobbles and boulders should be investigated to establish characteristics such as the flows necessary to move larger-sized sediment and their sediment transport.

- The impacts of a dam are not limited to rivers, but if the reservoir is large enough or close to the sea, the estuarine and marine environment can also be affected. It is recommended that the flood and sediment transport requirements of the estuarine and marine environment be investigated.

- It has been established that a range of flows is important in forming and maintaining the river geomorphology, but the relative importance between freshets and major flood releases in terms of the sediment transport need to be investigated.

- More data are necessary on the sediment transport of fine sediments and non-cohesive – cohesive mixtures in order to be able to test the theory developed during this project on the critical conditions for mass erosion.

- In order to calibrate the proposed cohesive sediment transport equation for a wider range of sediment sizes, data on other types of cohesive sediments are necessary.

- The effect of consolidation and drying of fine sediments on the sediment transport behaviour should be investigated in greater detail.