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Restoration of the Hex river to equilibrium morphological conditions

G.R. Basson

Department of Civil Engineering, University of Pretoria, Pretoria, 0002, South Africa

E-mail: bass-gr@fanella.ee.up.ac.za

Abstract

The Hex river near the town of Worcester, South Africa, has a braided character with wide floodplains, a steep bed slope and high bed load. In June 1996, one of the highest floods on record caused severe head cutting, scouring the river bed by two metres which caused instability problems at two bridges. A comprehensive hydraulic study has been undertaken to identify the problem causes and impacts, and to establish a long-term solution for river equilibrium and bridge safety. Man's involvement in altering the river include : extensive mining of boulders from the main river channel with the aim of reducing flood levels which was found to be the main reason for head cutting, construction of bridges with fixed bed levels, river channel alteration, the construction of groynes on the floodplain, and closing of a major part of the braided system for agricultural development.

The current braided river system has been modelled with a one dimensional mathematical model, which could accurately simulate the observed bed degradation due to the mining. Restoration of the scoured river bed has been achieved by constructing two weirs on the river in order to raise the bed level to its natural long-term equilibrium state. The bridges have been modified with fixed concrete beds at the elevation of the simulated equilibrium bed profile, with the addition of energy dissipation structures to prevent local scour.

1 Introduction

The Hex river, South Africa, originates in the Hex river mountains and flows through the Hex river valley, renowned for its table grapes. As the river leaves

the Valley it passes to the east of the town of Worcester before reaching the Breede river. It is on this lower part of the river which has an extensively braided character, with floodplains as wide as 500 m, on which this paper focuses. Originally the river was called the "harum-scarum" (direct translation) river near the town of Worcester due to the seemingly unpredictable changes in the river course from low to high flow conditions. A map dated 1891 indicates that the original course of the river was approximately 5 km to the east of its current position. Due to closure of that part of the braided system for farming purposes early in this century, a new morphological equilibrium was established in the remaining river. The river is however still attempting to break through to its old course as the cutoff has to be repaired regularly. The river is steep with a high bed load of boulders 100 to 150 mm in diameter. Typical flood flow velocities are as high as 3 m/s.

The main route between Worcester and Robertson crosses the Hex river floodplain just outside Worcester by means of twelve bridges. Canalization and development on the floodplain have concentrated the flow mainly through three bridges, located between Worcester and Zwelentemba, on river channels Hex1, 2 and 3.(Figure 1). The main rail link towards the east follows the same route as the road and at this point runs approximately 20 m away on the northern (upstream) side. Corresponding rail bridges are provided at all the road bridges.

Site investigations after severe flooding in June 1996 revealed extensive local erosion and also a deep erosion gulley located approximately 100 m downstream of the Hex1 road bridge. The situation was monitored on a regular basis and it was soon apparent that the gulley was rapidly progressing upstream. In view of the uncertainties involved and the importance of safeguarding this route it was decided to undertake a comprehensive investigation of the Hex river at this location. The study reach extended for a distance of approximately 2 km either side of the crossing point. The main objectives of this investigation were to determine maximum possible erosion depths and also develop effective long-term remedial measures.

2 Historical impacts on the river

In the current braided river system a number of developments impact on the river:

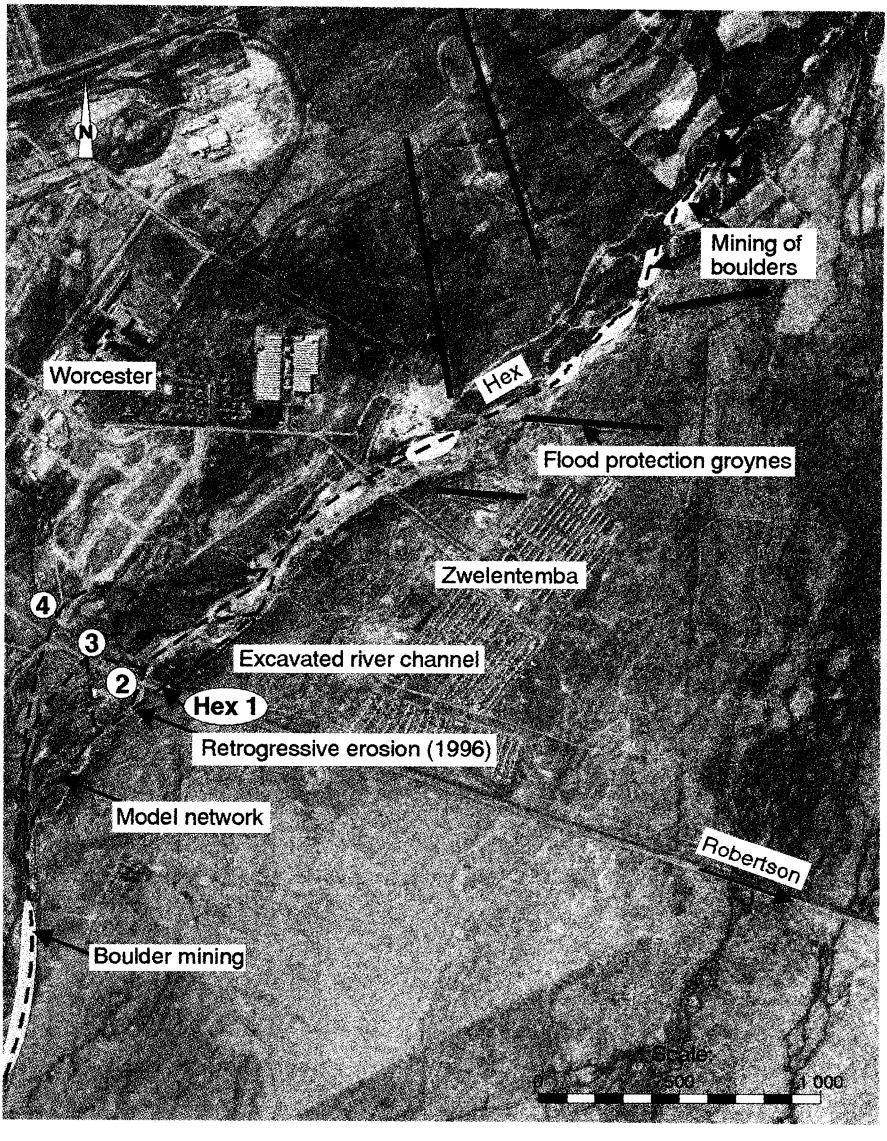

Figure 1: Location plan of Hex Rever near Worcester

- residential development on the floodplain has caused high risk of flood damage, especially at Zwelentemba. The local authority has for some years been mining boulders from the river in an attempt to lower flood levels.

- vineyards were regularly damaged along the river banks as it changed its main flow course, which was countered some 30 years ago by the construction of groynes at regular distances along the river which help to restrict excessive lateral movement of the river.

- Nine road and rail bridges were constructed in the 1950s straight across the widest part of the braided river to link the towns of Worcester and Robertson. Possibly due to local bed scour, the Hex2 road bridge river bed was replaced by concrete slabs, preventing local scour during floods. This local scour was associated with non-alignment of the duel bridge piers and bridge constrictions.

- Some 20 years ago it was found that very little flow occurred at the Hex1 bridge during floods and in order to distribute the flood flow mainly between three bridges, this channel was excavated.

3 Recent flood damage

During 1996 one of the highest flood peaks on record occurred in the Hex river and resulted in high flood discharge through the river channel Hex1 (see Figure 1). Downstream of the Hex1 bridges, the river banks were scoured 10 to 20 m wider, and head cutting lowered the river bed by as much as 2 m, within a distance of approximately 100 m from the road bridge. Very little flow occurred at the Hex4 bridges during the flood, and the flow distribution was such that most flow was through bridges 1, 2 and 3 without overtopping the rail or road. During the lower flow following the flood, the head cutting of Hex1 continued in a narrow deep channel of 6 m width, which by the end of the rainy season (October 1996) had cut back to underneath the road and rail bridges across Hex1. The road bridge pier foundations were scoured by 2 m, with only a narrow cohesive-boulder mass supporting the bridge piers, which necessitated quick action to save the bridge. Figure 2 shows a 1987 photograph of the Hex1 road bridge, while Figure 3 shows the impact of head cutting as experienced in 1996 at the same bridge.

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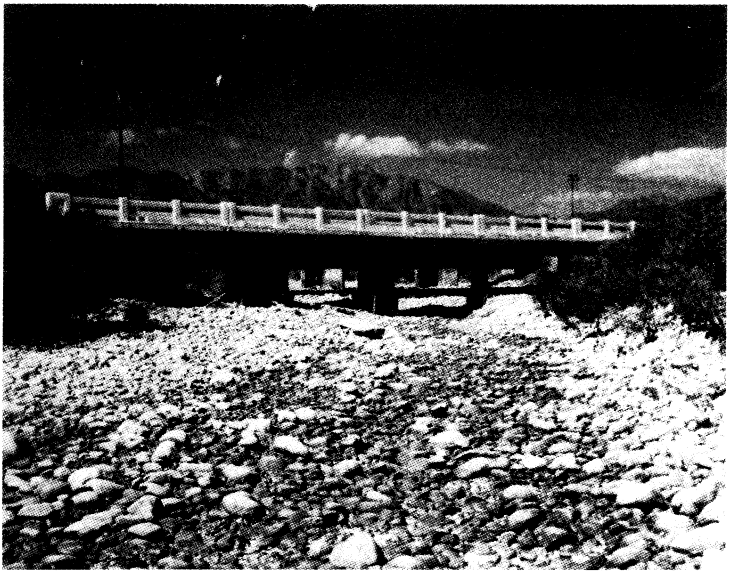

Figure 2: View of Hex1 Road bridge in 1987, looking upstream



Figure 3: View of Hex1 Road bridge in 1996, looking upstream

4 Hydraulic analysis

At first inspection one would expect bed and bank scour during a major flood, especially of Hex1 which has been mechanically opened to the braided river system. What was however puzzling was the continued retrogressive erosion during relatively small floods following the major flood, something which has never occurred before since the construction of the bridges. It was only after further investigation that the origin of the problem came to light: extensive boulder mining of the river some 800 m downstream, which has widened the river by 2 to 3 times its original width, and lowered the river bed by at least 2 m. This operation commenced 3 years ago with the main aim of lowering flood levels.

Other impacts on the hydraulics were:

- mining upstream of the bridges, limiting sediment availability and thereby creating under-saturated sediment transport conditions which result in increased erosion downstream.

- fixed bridge bed of Hex2 bridges caused reduced flow through this "main" channel of the braided river system as bed erosion during floods was restricted.

- bridge constrictions, with debris (due to deforestation) accumulated against the piers, caused supercritical flow conditions downstream of the bridges and excessive bank scour.

5 Mathematical modelling of the river morphology

The aims with the mathematical modelling of the Hex river system were to establish the morphological reasons why the river bed changed so dramatically during recent floods, as well as investigate future remedial actions to be taken. A one dimensional numerical model suitable to model multiple channels in the braided river, with the capabilities of modelling non-cohesive and cohesive bed erosion processes and bed load sediment transport, has been used. Simons and Richardson[2] remarked on the difficulty of modelling a braided river system: "The braided stream is difficult to work with in that it is unstable, changes its alignment rapidly, carry large quantities of sediment, is very wide and shallow

even at flood flow and is, in general, unpredictable". From an inspection of a series of old aerial photographs, stable main river channels could however be identified (see Figure 1) which have been used in the multiple channel modelling.

The model was firstly calibrated against observed flood levels and the critical condition for bed erosion of the consolidated cohesive bed was established based on a dominant flood of 460 m^3/s (1 in 10 year recurrence interval) and a survey of 1985 which represents a long-term equilibrium (before the impact of downstream mining). This calibrated model was then used to simulate the morphological changes due to the mining activity downstream of the bridges. A simulated long-term bed profile is shown in Figure 4 which compares well with the observed bed profile.

Due to the limited field data and the need to give answers as soon as possible with the risk to road and rail, certain assumptions had to be made with regards to sediment transport, possible bed armouring and erosion. Although bed load dominates the sediment transport process in the Hex river, fine suspended sediment are also present during floods. Old deposits consist of a conglomerate of fine sediment and boulders at high density, which limits re-entrainment of the sediment once consolidated.

In the modelling a calibrated critical shear stress for erosion of the cohesive sediment of 150 N/m^2 was used, based on the preflood bed conditions, which is relatively high considering typical values < 10 N/m^2 for estuaries, or 80 N/m^2 for cohesive consolidated reservoir sediment under flood flushing conditions. Basson[1].

6 River restoration to equilibrium morphological conditions

The mathematical model simulation of long-term morphological conditions in the Hex river indicated the following:

- The river bed at the Hex1 bridges would rise naturally, creating a smaller river gradient upstream and thereby reducing the flood discharge in this channel. In fact the model indicates that in the long term this channel would want to close completely, as was the case before it was opened mechanically in the 1970s. In the short term, however, the Hex1 channel and bridges would have to withstand highly erosive conditions.

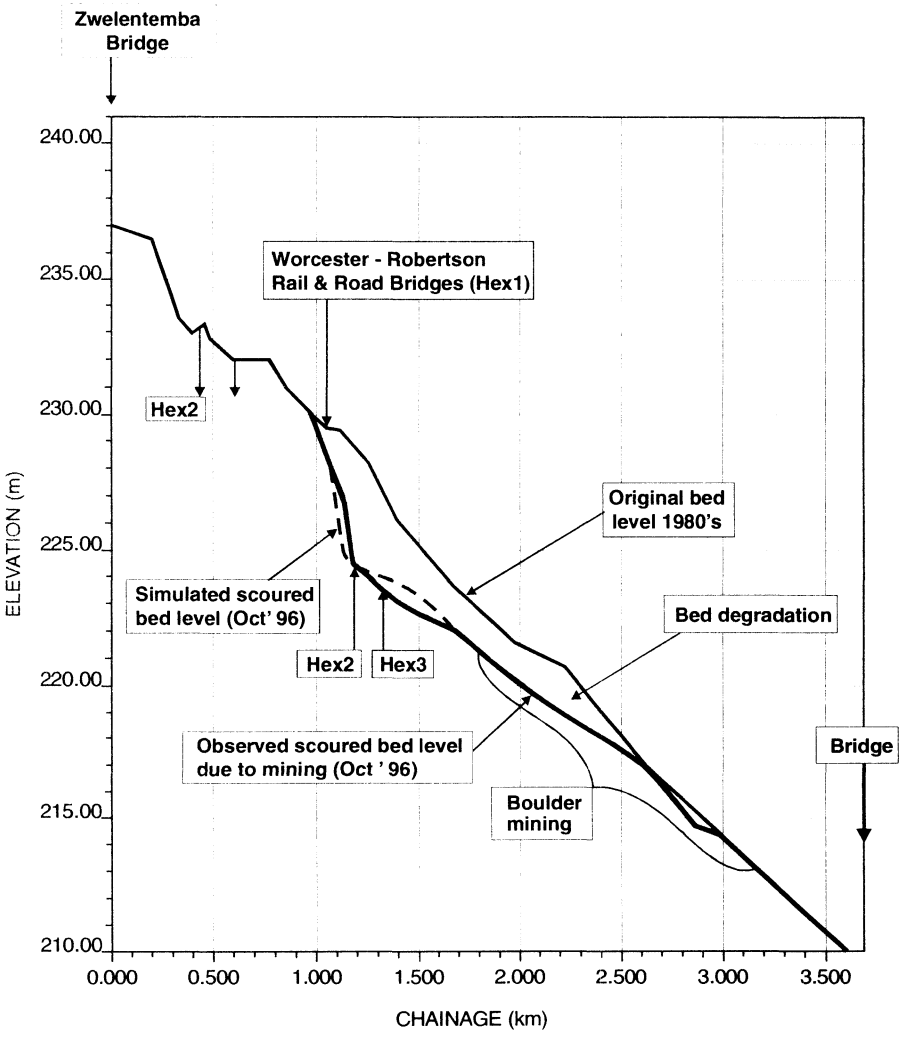

Figure 4: Hex1 longitudinal profile with observed and simulated bed levels

- head cutting should terminate just upstream of the Hex1 rail bridge as the constriction causes some reduction in the sediment transport capacity and erosive power upstream of the bridge.

Engineering solutions to safeguard the bridges have been based on the natural river equilibrium:

- stilling basins have been designed directly downstream of each of the road bridges (Hex1, 2 and 3), which will dissipate energy and prevent local bed and bank erosion downstream of the bridges.

- the Hex1, 2 and 3 bridge beds have been fixed by mass concrete at the simulated equilibrium bed levels.

- River banks have been protected by riprap of up to 2 tons at a bank slope of 1:4 (vertical to horizontal)

- The impact of the downstream boulder mining has been mitigated by constructing two low weirs on Hex1, 200 m and 400 m downstream of the road. These concrete weirs of 1,2 m drop each will raise water levels during a flood to what it should have been under natural conditions. The reduced sediment transport capacity upstream of the weirs will cause deposition of sediment which will consolidate with time and form a new consolidated bed with morphology corresponding closely to the natural river equilibrium. Although this project focused on the road and rail bridges, with localized morphological restoration, an extended study is underway to address more global changes to the river equilibrium.

7 Future management of the Hex river

The number of parties involved directly in damage caused by man's changes to the Hex river, makes an immediate coordinated solution difficult to achieve. These parties, which include the Provincial Administration Western Cape, Department of Transport, Worcester Municipality, Spoornet, Department of Mining, Department of Water Affairs and Forestry, Hex River Irrigation Board, and Breede River Regional Council, however agree that a coordinated

morphological analysis of the Hex river should be carried out, with the aims to prevent future structural damage, flooding and river damage.

Future river management should control mining activity (if allowed at all). In the past, mining was mainly undertaken as it was believed it would lower flood levels. Ironically, this study has found that the mining caused very little reduction in flood levels, but had a severe impact on the river network flow distribution, degradation of the bed and sediment transport balance.

Ultimately one would want to restore the river system to its original river course as was found on old maps dated 1891. This will, however, be quite difficult due to the socio-economics of current floodplain development.

8 Conclusions

The study showed that a mathematical morphological model can be used successfully to model the most complex nature of a braided river system. Furthermore, the impacts of man's involvement with the river, such as mining, could be simulated accurately, and mitigation to natural equilibrium conditions has been possible. Future bridge safety has been addressed by first ensuring the long-term equilibrium river morphological conditions are met, thereby limiting the impacts of the river on the bridges and vice versa.

9 Acknowledgements

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References

1. Basson, G.R. *Hydraulics of reservoir sedimentation*, PhD dissertation, University of Stellenbosch, 1996.

2. Simons, D.B. & Sentürk, *Sediment Transport Technology, Water and Sediment Dynamics*, Water Resources Publications, Colorado, USA, 1992.