APPENDIX E:
GEOMORPHOLOGY

Compiled by Mark Rountree, Fluvius Environmental Consultants

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E1 INTRODUCTION

This report describes the specialist data analysis for the geomorphological component of the Orange River Environmental Flow Assessment study undertaken in 2010. The report includes the EcoClassification ("health") assessments of the EFR sites, and the analysis undertaken to identify significant flows for channel and habitat maintenance.

E1.1 Site Information

Eight sites were selected for the Environmental Flow Assessment within the study area. Sites were selected to represent reaches of the various Resource Units which were identified within the study area. Field assessments were conducted at each of the EFR sites during the low flow season of 2010. This enabled detailed assessments of the planform, morphology, and bed sediment distributions to be undertaken. These data were then used in conjunction with available literature and desktop information to undertake EcoClassification assessments and to enable analyses of the potential bed material transport to identify important flow classes for channel and bed maintenance.

E1.2 Sediment distribution at the sites

Rapid assessments of sediment size distribution were conducted at each of the EFR sites. The different sediment distributions can have an impact on the size and frequency of flows required to maintain bed mobility and sediment transport at each site, since the size of the sediment dictates the energy of the floods required for channel maintenance (Table E1).

Table E1 Sediment size distribution at the EFR sites

EFR Site	Percentile of Sediment Size Distribution (sediment diameter in mm)				
	D5	*D16*	*D50*	*D84*	*D95*
1	*Not sampled - only EcoClassification Assessment at this site*				
2	*0.5*	*0.5*	*50*	*100*	*150*
3	*5*	*20*	*80*	*200*	*270*
4	*0.2*	*0.2*	*0.2*	*20*	*50*
5	*0.2*	*0.2*	*2*	*100*	*200*
6	*0.2*	*0.2*	*1*	*30*	*70*
7	*0.2*	*10*	*50*	*80*	*110*
8	*Bed sediment not sampled - wetland system with peat bed*				

E2 ECOCLASSIFICATION OF THE SITES

The Orange River has very high rainfall headwaters in Lesotho and the central and south-central interior of South Africa. These areas also coincide with very high sediment yield zones (Figure E1). The river flows northwest, forming the border between South Africa and Namibia. In the lower reaches, low rainfall sediment yield is extremely low due to the low and infrequent rainfall.

Large dams in the upper and central catchment have caused significant reductions in floods relative to the natural flow conditions. Concomitant with the reductions in floods are the large-scale reductions in sediment supplied to downstream reaches, both through sediment trapping in the dams and due to apparent natural decreases in sediment availability in the catchments (Rooseboom and von M. Harmse, 1979).

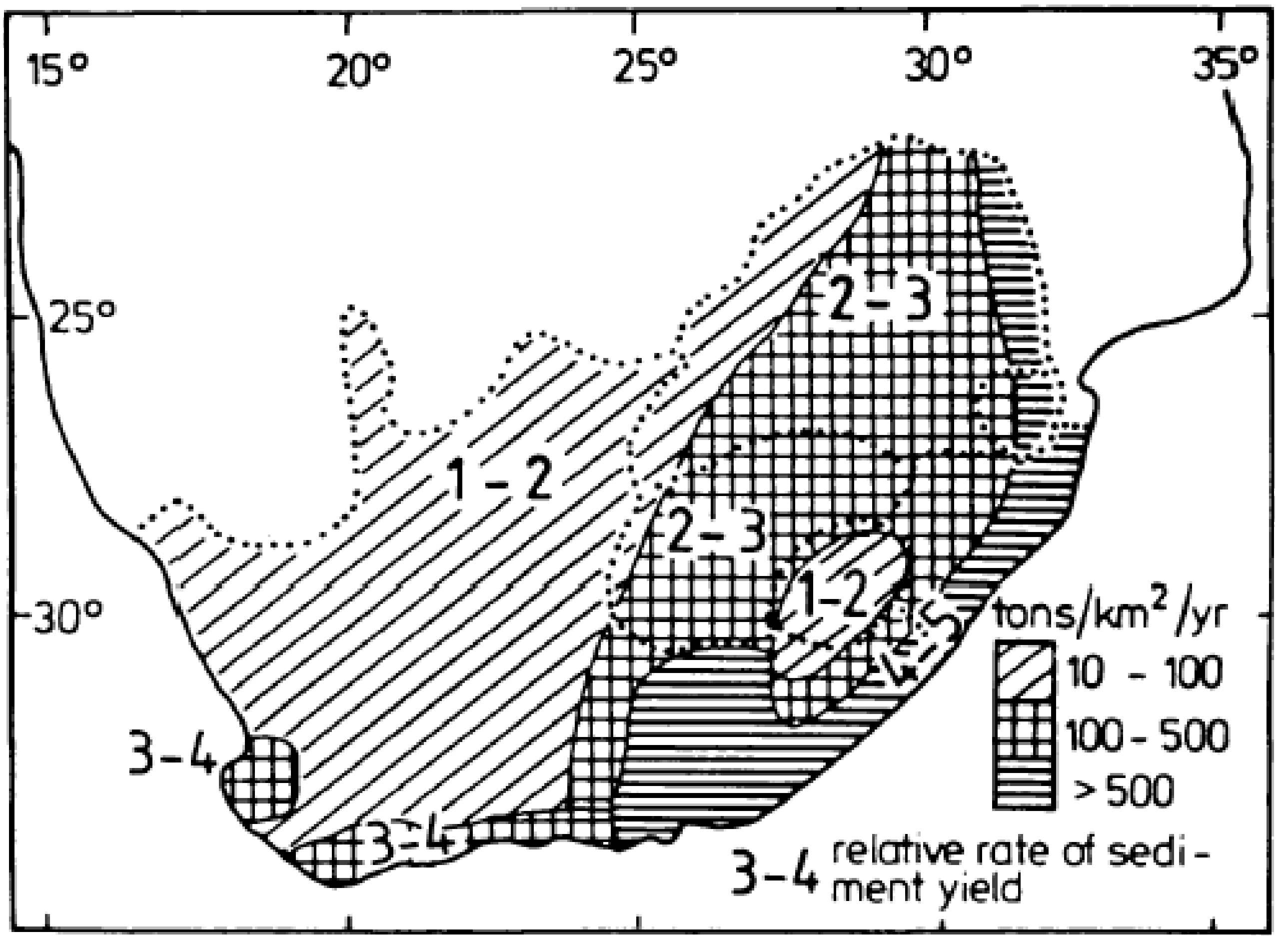


Figure E1 Broad Sediment Yield zones for South Africa; 1= very low, 2 = low, 3= moderate, 4= high, 5= very high (after Rooseboom and Lotriet, 1992).

The morphological impacts of reduced floods are ameliorated by the effects of reduced sediment loads and vice versa, since morphology is determined by the interaction of flow and sediment. Additionally, the mainstem Orange River morphology is extensively bedrock controlled and this affords high morphological resilience to flow and sediment impacts. At the EFR sites on the mainstem Orange River (EFR O1 - 4), this amelioration of flood-sediment impacts and morphological resilience has resulted in relatively high EcoStatus (ecological condition) scores for Geomorphology despite the extreme changes in hydrology that have occurred in the system.

E2.1 EFR O1: HOPETOWN

E2.1.1 Available data

A historical aerial photographic record dating back to the 1950's, and coarse scale map from 1905, was available for this site (Table E2) and these data were used to assess the Reference conditions of the site. The nearest gauge is 70km downstream, but this is broadly representative of the flows at the site. Confidence in the site assessment is low because site visit was rapid, and hydrological data are not clear (sub-daily data needed to assess the impact of peaking at the site, and this is not available).

E2.1.1 Reference Condition

Under Reference Condition (100 – 200 years ago), this reach of the river probably was a braided reach (as indicated in the 1950's and 1960's aerial photos), with multiple channels of gravel, cobbles and sand. The banks would have been well-vegetated, but we expect that the bars would be poorly to moderately vegetated as large floods would scour and rework these deposits.

E2.1.2 Description of the current condition

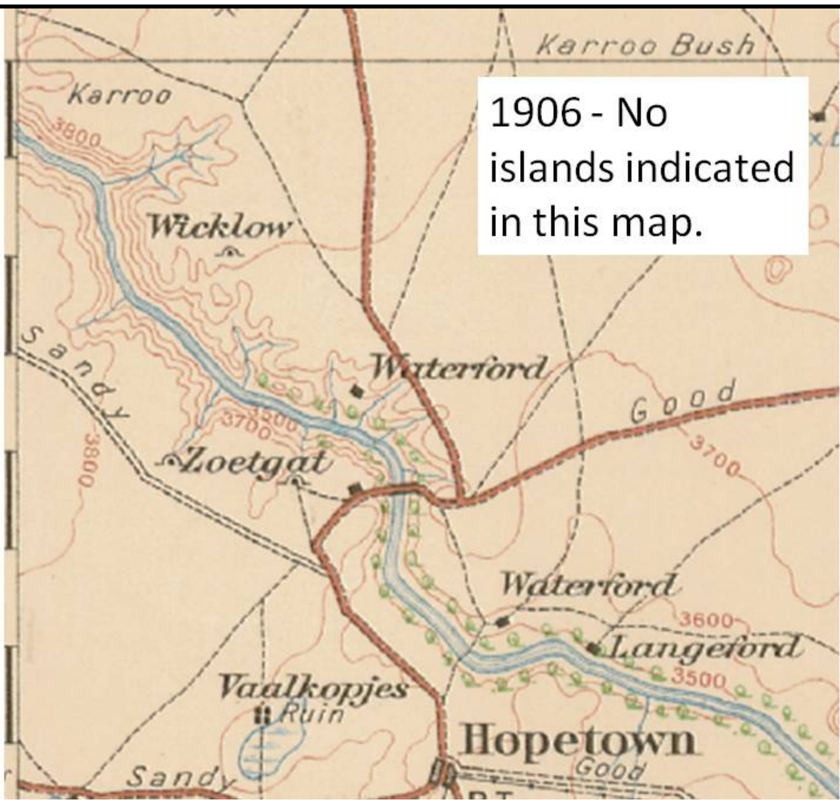
Present Day[1] flows in this section are about half of the MAR – this due to a number of very large upstream dams and associated diversions and abstractions. A peaking hydro-power dam operates about 100km upstream of the site with twice-daily floods. At the site, much attenuation of these peaks is expected to have occurred. Despite the daily floods associated with peaking power, large flood sizes and frequencies are highly reduced. This explains the increase in the area of bars and islands in the reach observed over the historical record, and especially the progressive stabilisation of the sedimentary features by vegetation. Scouring events across these bars are too infrequent and small to keep sedimentary and vegetation encroachment in check.

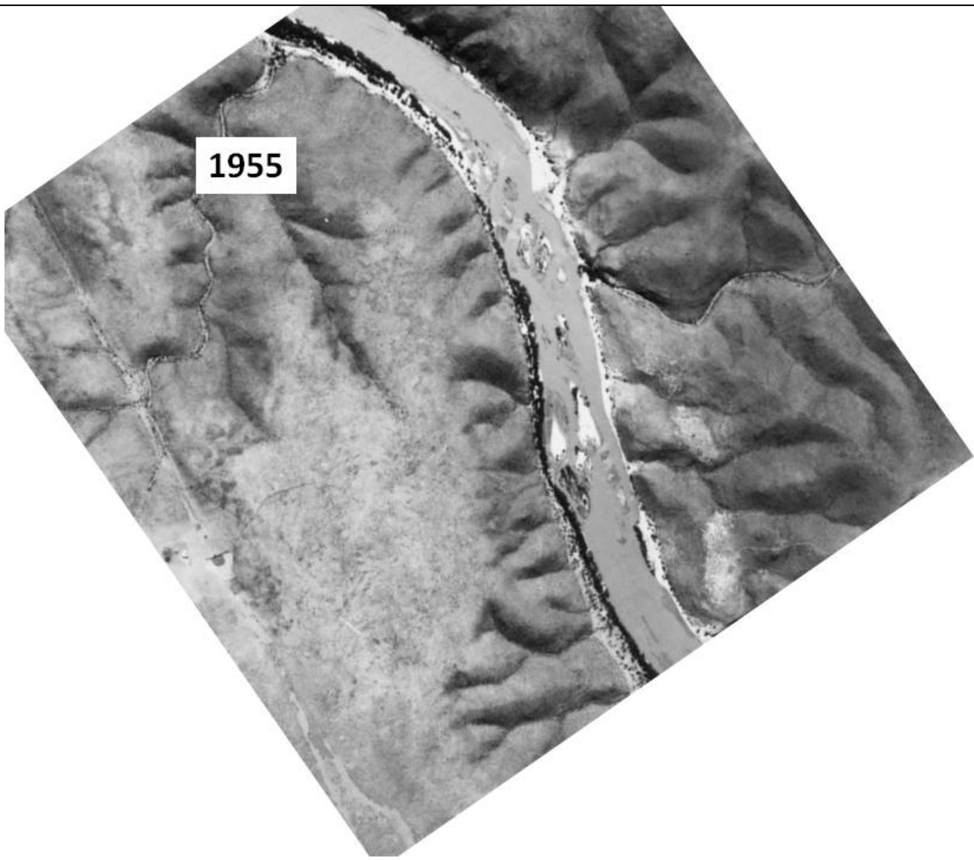
Despite the severe erosion and elevated sediment loads arising from some sections of the catchment, the large dams along the mainstem would serve to reduce sediment load. The increased expansion of bars and islands (rather than erosion) suggests that the decreased transport potential (due to reduced flows) has been more critical than the reduced sediment supply (due to trapping in upstream dams).

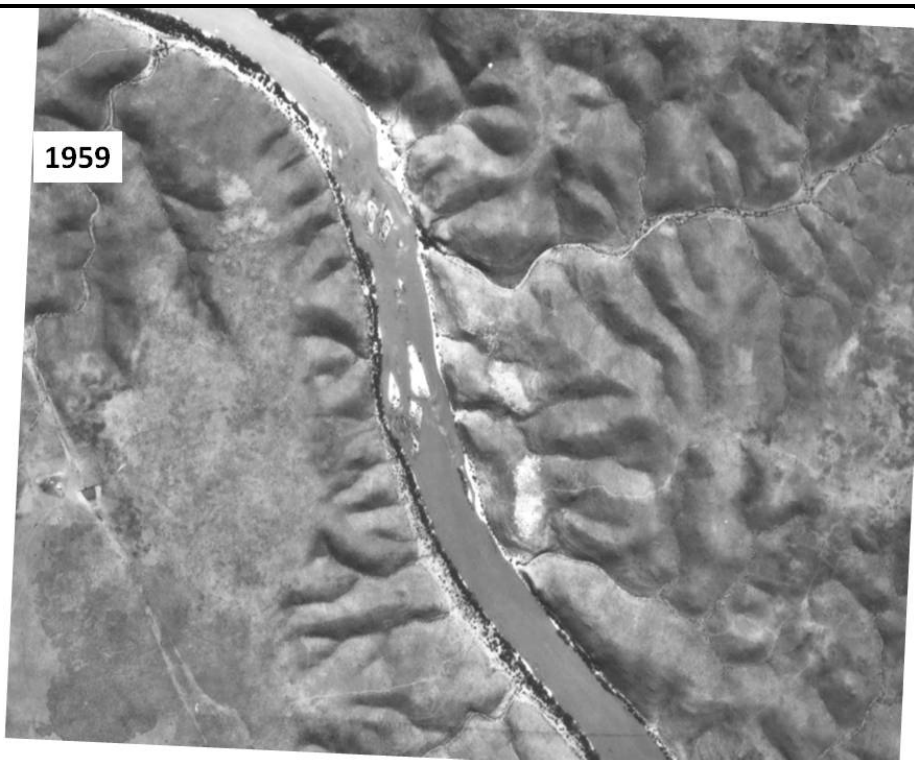
Figure E2 The banks and mid-channel bars at EFR O1 are well-vegetated

[1] Present day assumes Lesotho Highlands Phase 1a and 1b are in operation, although actually these only started in mid-2009, so observed flows are higher than the modelled PD, and this may also account for the slightly better than expected PES score.

Table E2 The historical map (1906) and historical aerial photographic record for EFR O1



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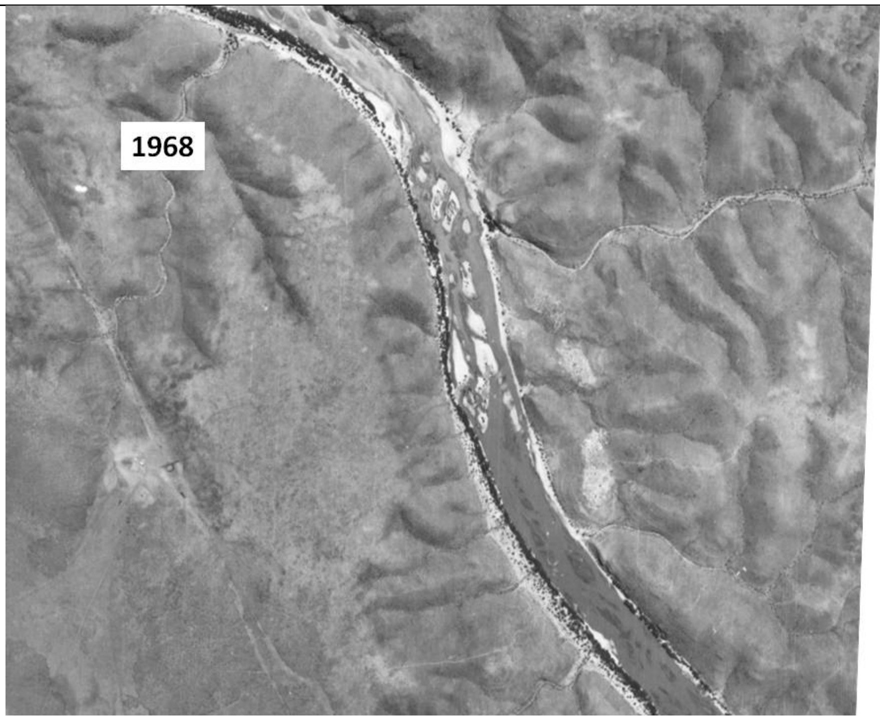
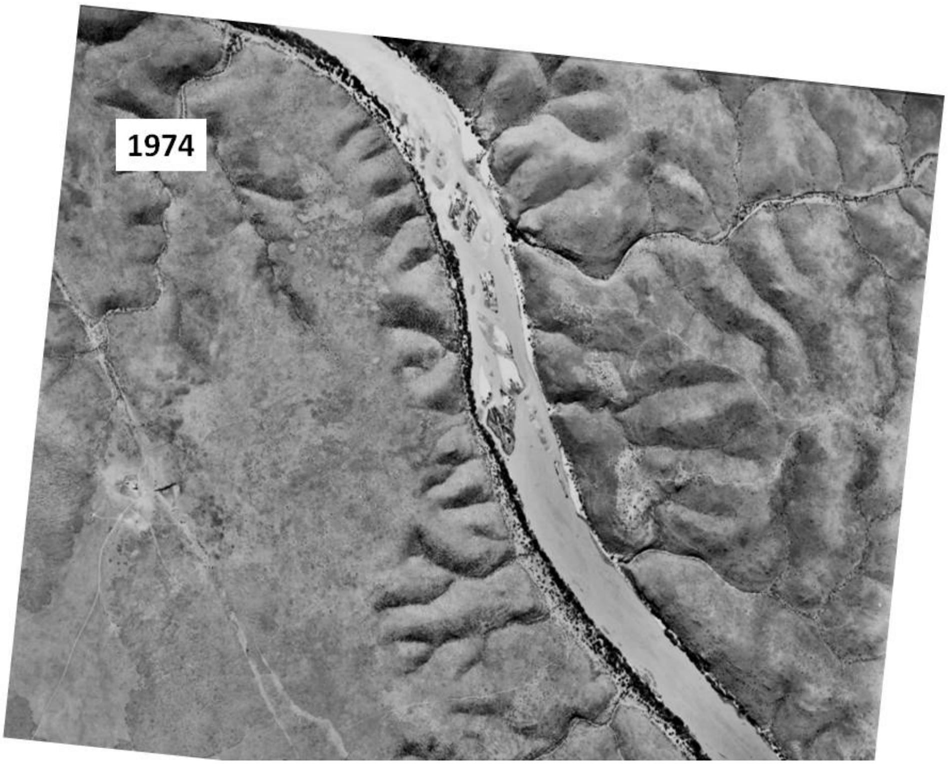
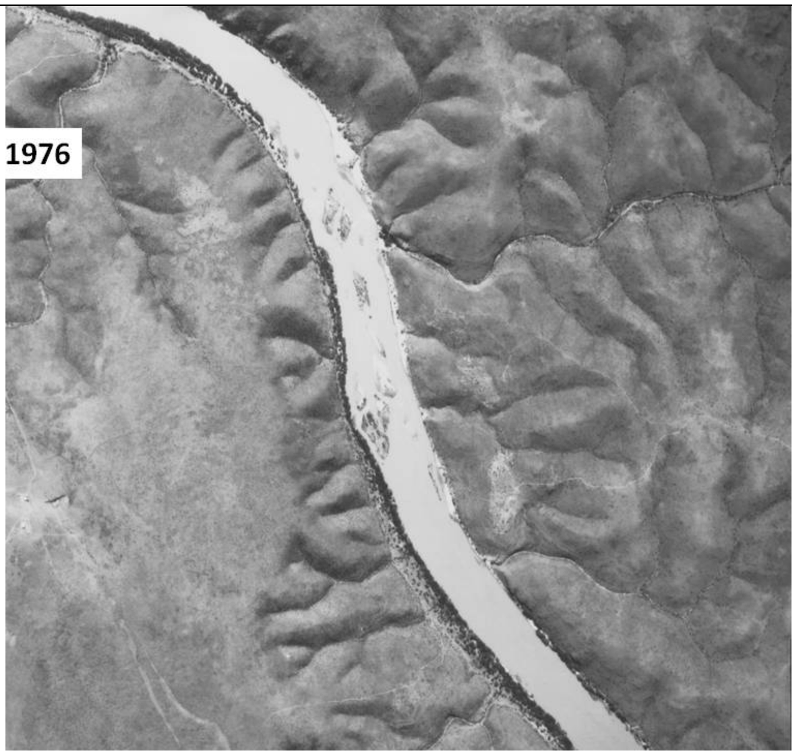

1968


1974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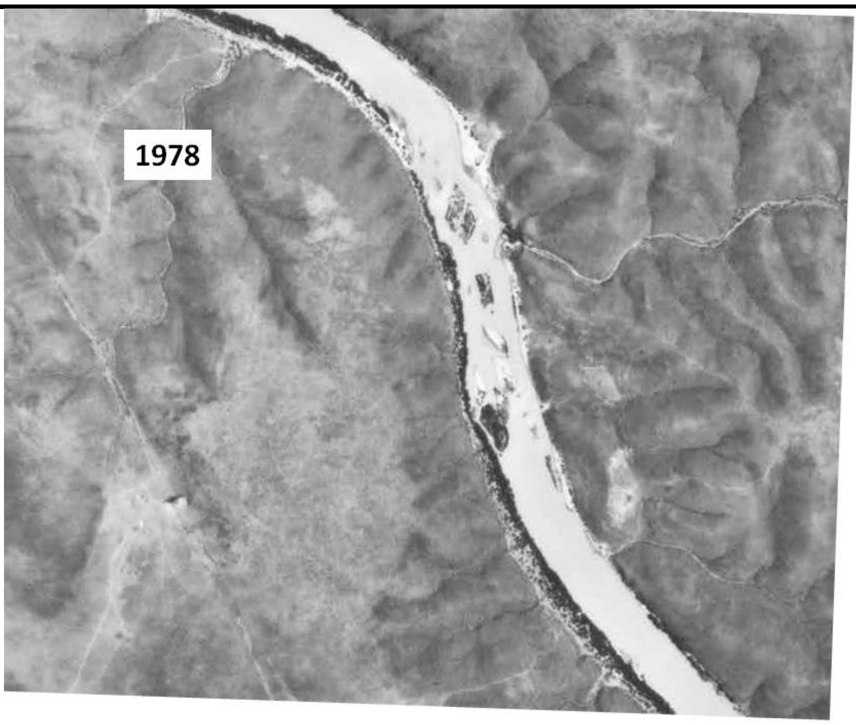
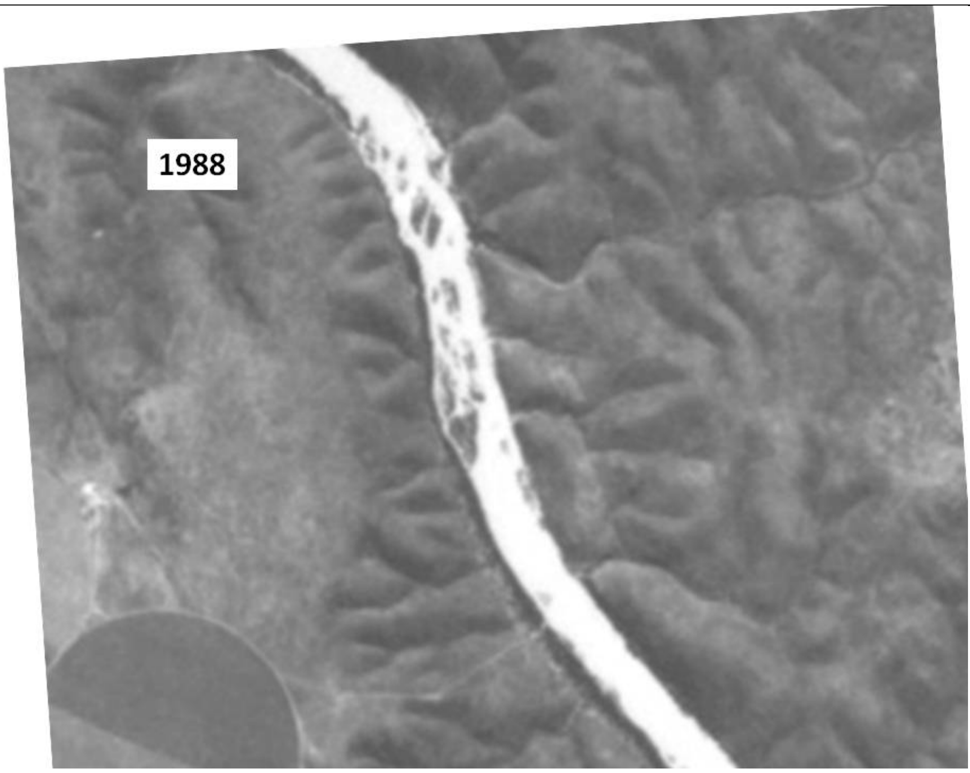
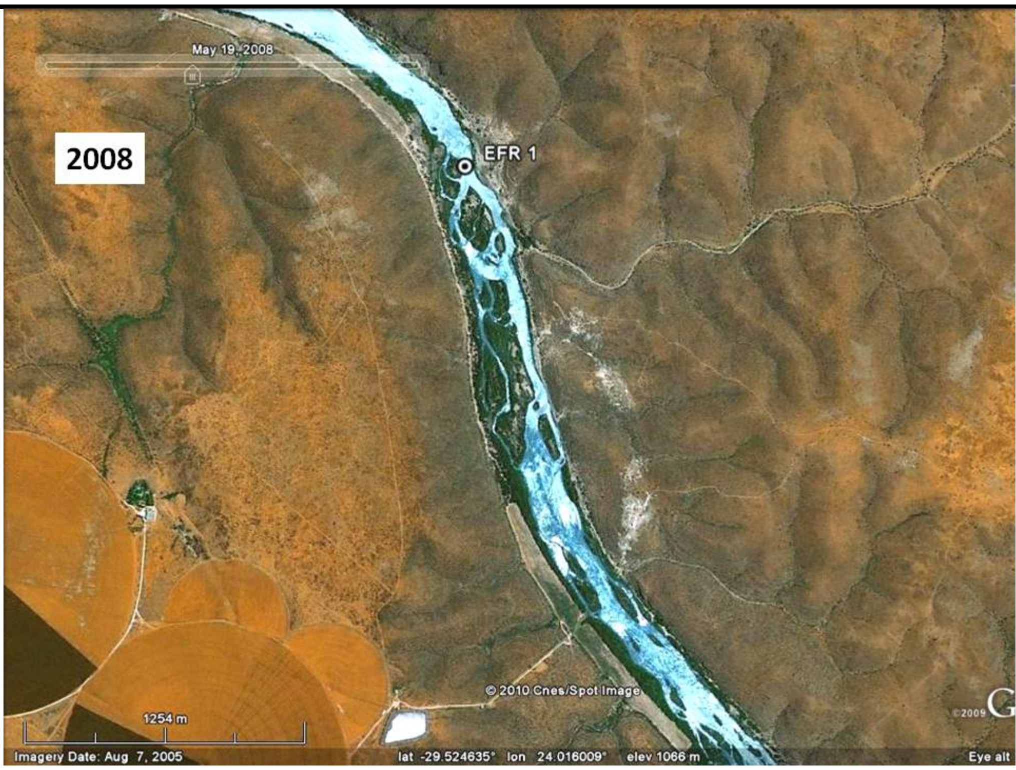

1978


1988



E2.1.3 Present Ecological State Category

The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES is in a C/D (59%) because:

- Although there are increased sediment loads from the upper catchment, much of this is trapped in the upstream dams, but tributaries and flushing of fines and suspended load through the dams compensates for some of the reduced sediment supply downstream. Additionally, large floods are reduced, so the reduced sediment is somewhat offset by a reduced frequency of large scour events.
- Moderate floods now occur as twice-daily flows due to peaking hydropower generation, and this has likely armoured sections of the channel, but may be responsible for the increased vegetation in the lower riparian zones due to more frequent wetting.
- The increased extent and stabilisation of the alluvial bars could be reversed with more natural flood releases.

E2.1.4 Trends

The overall trend for the Geomorphology is weakly negative. The reach (extending down to the confluence with the Vaal) is likely to still be adjusting to the peaking flows and flushing of sediments in the zone below the dam.

E2.2 EFR O2: BOEGOEBERG

E2.2.1 Available data

A historical aerial photographic record dating back to the 1930's was available for this site (Table E3). This documents gross morphological changes to the site. A long flow record also dating from the 1930's until present day is available for a gauge near the site, and this can be used to represent flows at the site.

E2.2.2 Reference Condition

The gross morphology of the site is close to the Reference conditions, as indicated in the early 1930's aerial photographs of the site. The site was a bedrock anastomosing reach, characterised by multiple distributaries separated by very stable, vegetated bedrock core bars. Within the active channels, local slopes are steep and sediment deposition would be inhibited such that sandy sedimentary features would be limited to lee areas and low-energy marginal zones. Backwaters would be common.

E2.2.3 Description of the current condition

This is a bedrock anastomosing reach, with well-vegetated bedrock core bars and islands between the distributary channels, and large bedrock riffle areas in the active channels. Distributaries are generally stable with reach planforms controlled by local weaknesses in the underlying geology (Tooth and McCarthy, 2004). Anastomosing reaches of rivers have been shown to be relatively stable over long periods; being only 'reset' or scoured across the entire macro-channel flood by extremely large, infrequent ("catastrophic') flood events (Rountree *et al*., 2001, Rountree and Rogers, 2004). Therefore very large floods are required to maintain these reaches.

Present Day flows in this section are less than half of the MAR – this due to a number of very large upstream dams and associated diversions, and the extensive abstractions along the middle and lower reaches, as well as the now minimal input from the Vaal catchment. Flood sizes and frequencies are highly reduced (Figure E3) whilst baseflows have been stabilised and low flows elevated above natural conditions (Figure E4).

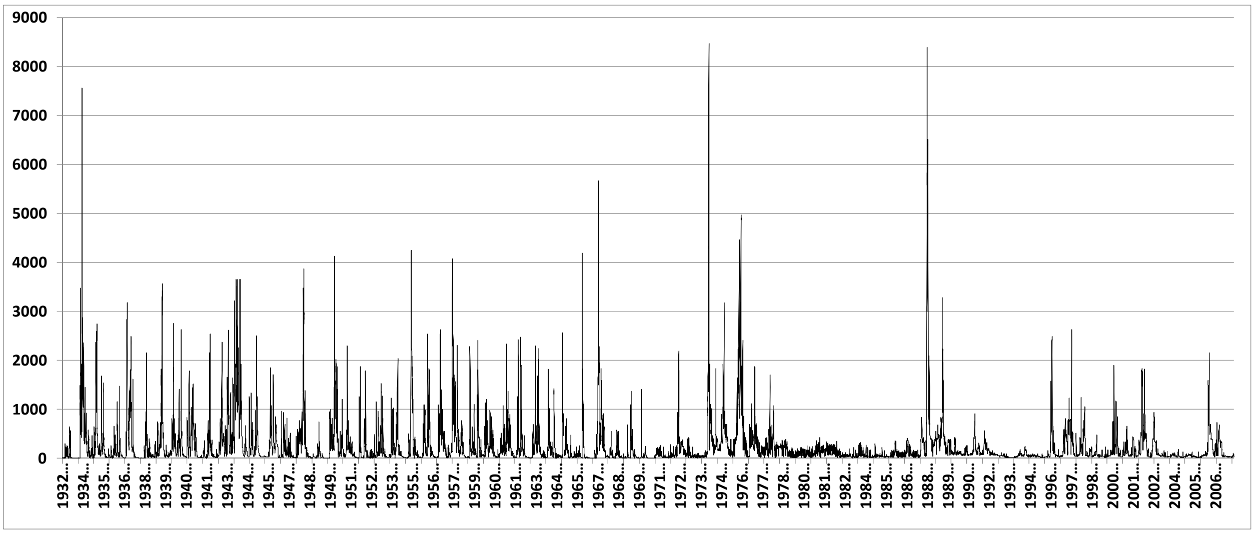


Figure E3 After the large dams in the upper catchment were completed in the 1960's and 1970's there was a severe decline in the magnitude and frequency of large floods

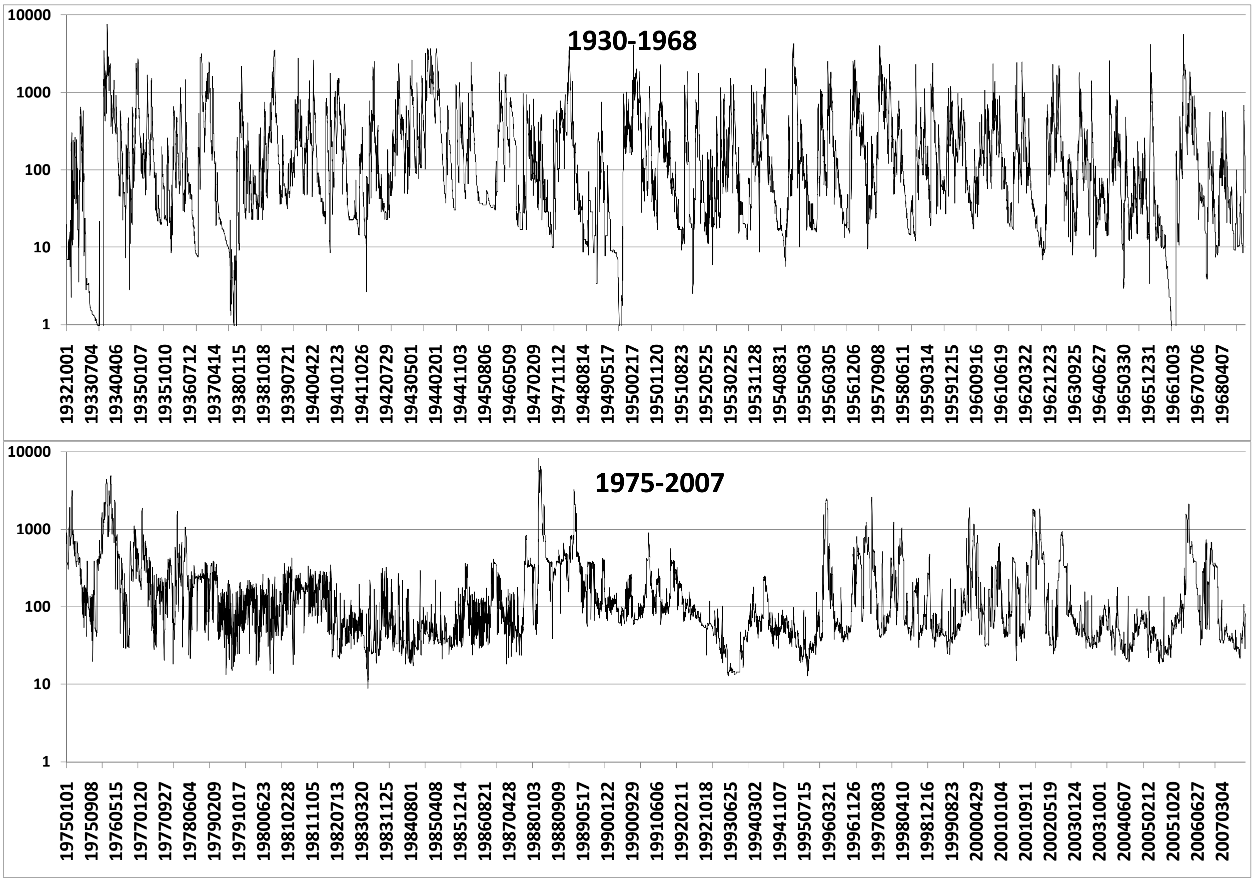


Figure E4 Observed hydrology on a log-scale for the periods 1930-1968 (pre-large dams) and 1975-2007 (post-large dams) indicating flow stabilisation and elevated low flows that have occurred in the 1975-2007 period after large dams were constructed in the upper catchment

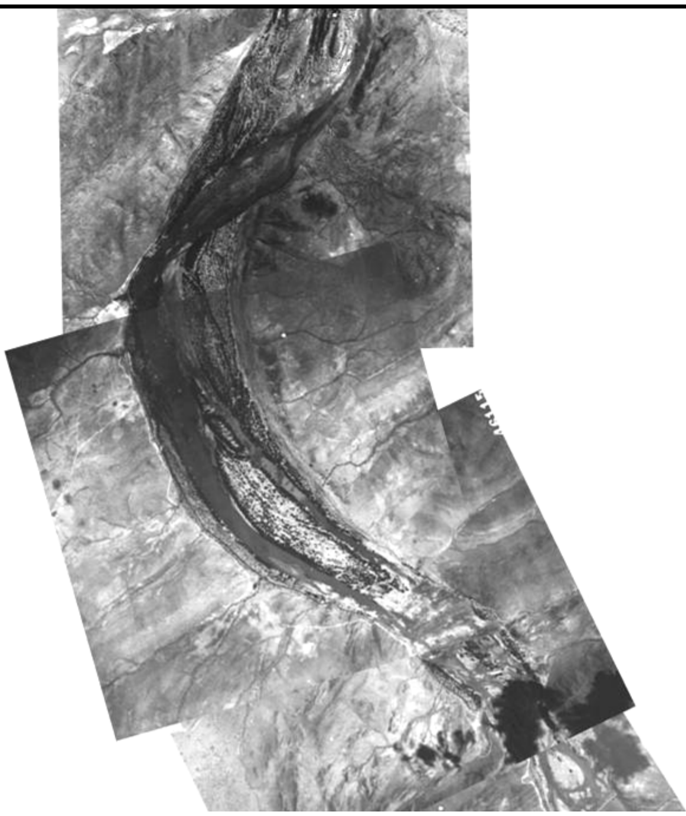
Despite the severe erosion and elevated sediment loads arising from some sections of the catchment, the several very large dams along the mainstem would serve to reduce sediment load. In anastomosing reaches such as this site, the local slopes tend to be high and transport capacity of the reach well in excess of available sediment supply. In-channel adjustments to reduced sediment supply (due to trapping in dams) are therefore likely to be small.

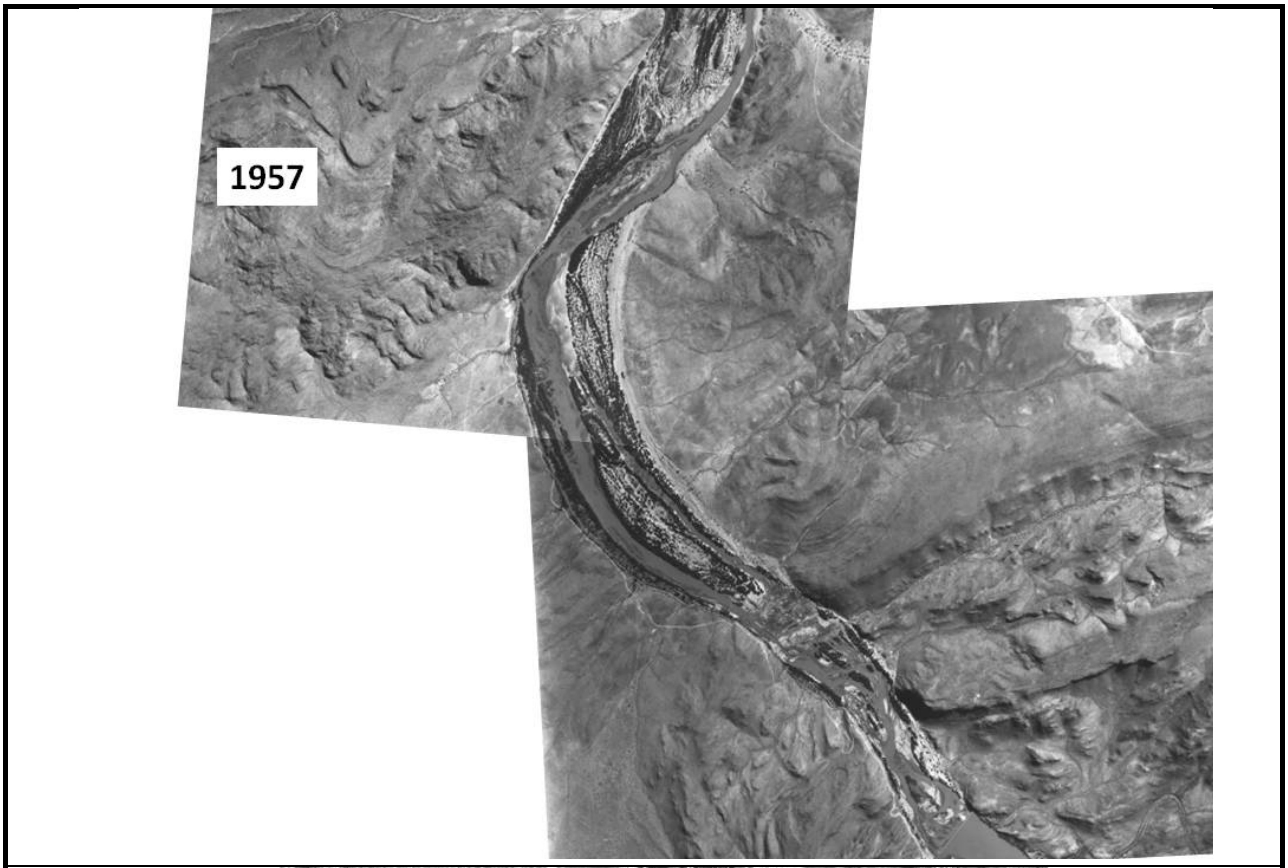
Annual flushing of the upstream dam also reintroduces some of the trapped sediments into the channel; albeit that this periodic high sediment load causes extensive fish kills.

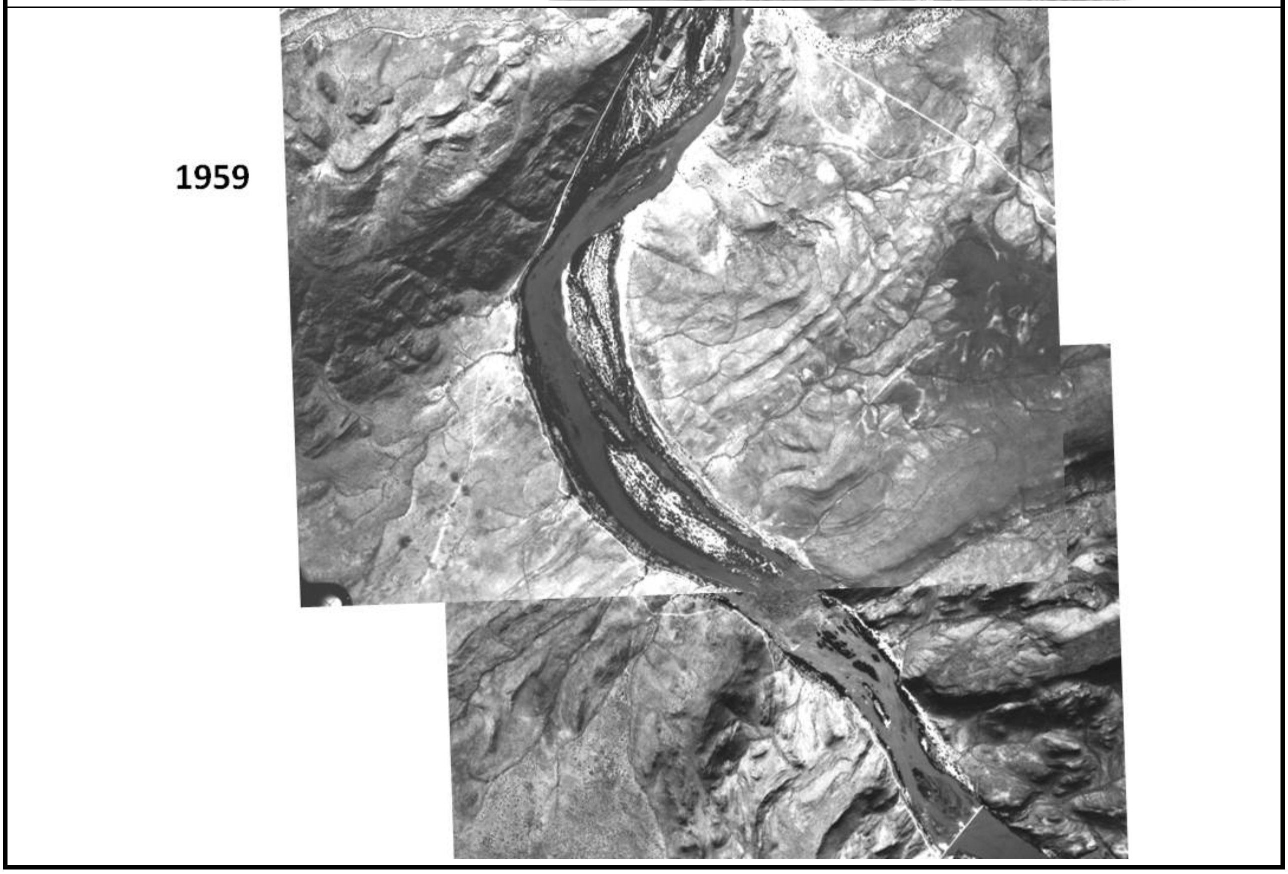
Figure E5 There is a high degree of physical habitat diversity associated with the numerous distributary channels at this site

Table E3 The historical aerial photographic record for EFR O2

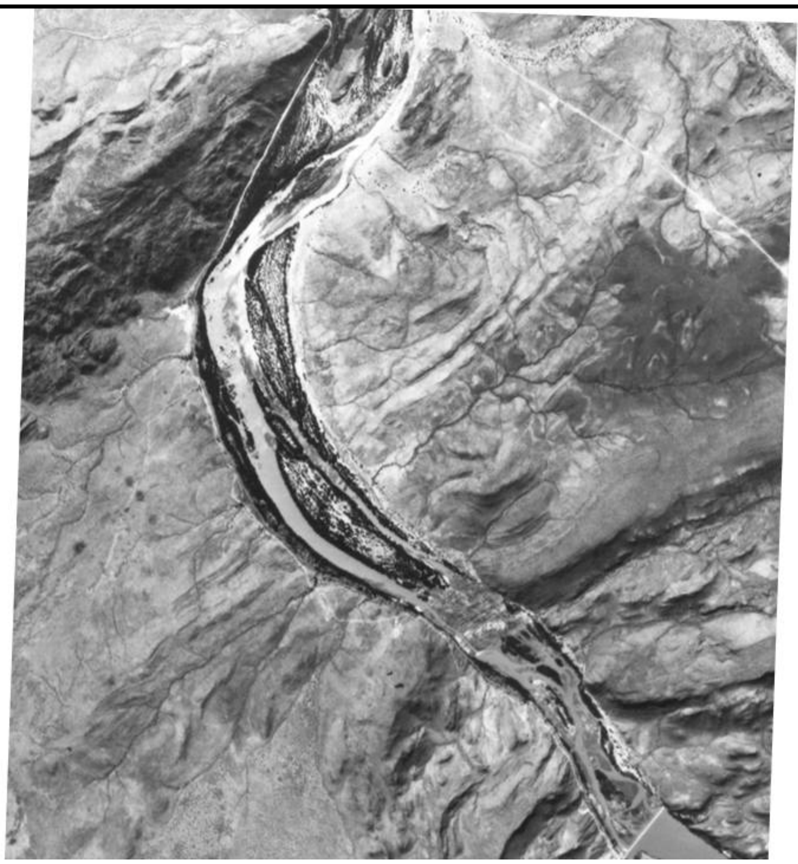
1938



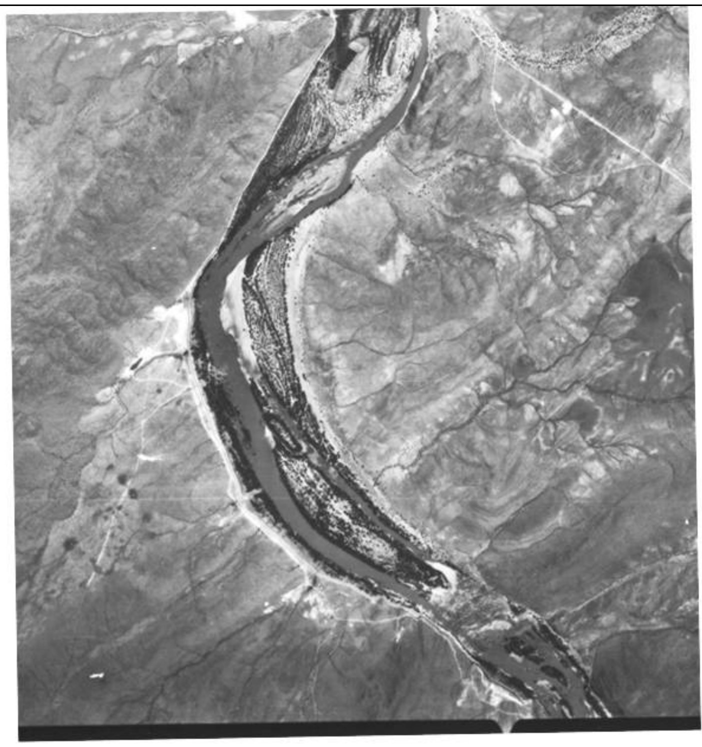

1957


1959

1964



1970



1976	
1981	

E2.2.4 Present Ecological State Category

The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES of the Geomorphology is in a C (73%) because:

- Although the flows are critically reduced at the site, this has been in some ways compensated for by the reduced sediment loads (since much is trapped in upstream dams). The site is however, not generally very sensitive to the impacts of baseflow and small flood changes, nor to small changes in sediment load.
- The key issue for this site is the loss of large floods that scour and maintain the distributary channels and beds. The very large dams now in place in the upstream catchment will probably prevent any sufficiently large scour events to occur in future, and thus stabilisation and increasing vegetation on the lower banks and bars will occur in the future.
- There are some indications in the historical aerial photographs of slight encroachment of vegetation in to the channels.

E2.2.5 Trends

The overall trend for the Geomorphology is stable.

E2.3 EFR O3: AUGRABIES

E2.3.1 Available data

A historical aerial photographic record dating back to the 1940's was available for this site. This documents gross morphological changes to the site and aids in the Reference State and PES determinations and assessments.

The nearest discharge gauge (D7H014) is 80kms upstream of the site, but this has a relatively short record (starting in 1993). The D8H004 gauge is approximately 85kms downstream and this record starts in 1971 and runs to 2010. This latter gauge was utilised to represent flows at the site since there are few significant tributaries and the record is much longer and therefore better able to represent long term flow conditions.

E2.3.2 Reference Condition

The historical aerial photographic record indicates the planform of this pool riffle and rapid reach is very stable. This stability is not unexpected given that much of the reach is bedrock controlled. The aerial photographic records also interestingly records some severely low flow periods in the 1960's, and an apparent zero flow in 1969.

E2.3.3 Description of the current condition

Present Day[2] flows in this section are less than half of the MAR – this due to a number of very large upstream dams and extensive abstractions along the middle and lower reaches, as well as the now minimal input from the Vaal catchment. As with EFR O2, flood sizes and frequencies are highly reduced, with even floods up to the 1:10 year possibly being attenuated upstream.

Sediment loads from the upper Orange are high; often elevated above natural conditions due to intensive settlement and poor land management. However despite these elevated sediment loads, the several very large dams along the mainstem trap most sediments and reduce the sediment load. Some dams flush out accumulated sediment to minimize storage loss. This enables some connectivity of sediment to the downstream reaches, but if undertaken during low flow periods, can cause fish kills downstream. Sediment flushing should occur during high flow periods in order to allow for dilution of the accumulated sediments.

Suspended fine sediment loads are extremely high, but at the site, cobbles, boulders and gravels in the channel and along the margins are generally not embedded, although they are slightly armoured. This suggests that scouring of the bed is occurring frequently enough that the bed is remaining mobile, but it is important to note that a very large flood had occurred in the wet season prior to the site assessments.

E2.3.4 Present Ecological State Category

The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES of the Geomorphology is in a C condition (71%). The reasons for this are that the critically reduced flows at the site constrain channel and habitat maintenance. However, despite the lower flows, decline in PES is ameliorated by:

- Coincident declines in sediment loads (since much is trapped in upstream dams), although some sediment replenishment occurs from tributary inputs.

[2] Present day assumes Lesotho Highlands Phase 1a and 1b are in operation, although actually these only started in mid-2009, so observed flows are higher than the modelled PD, and this may also account for the slightly better than expected PES score.

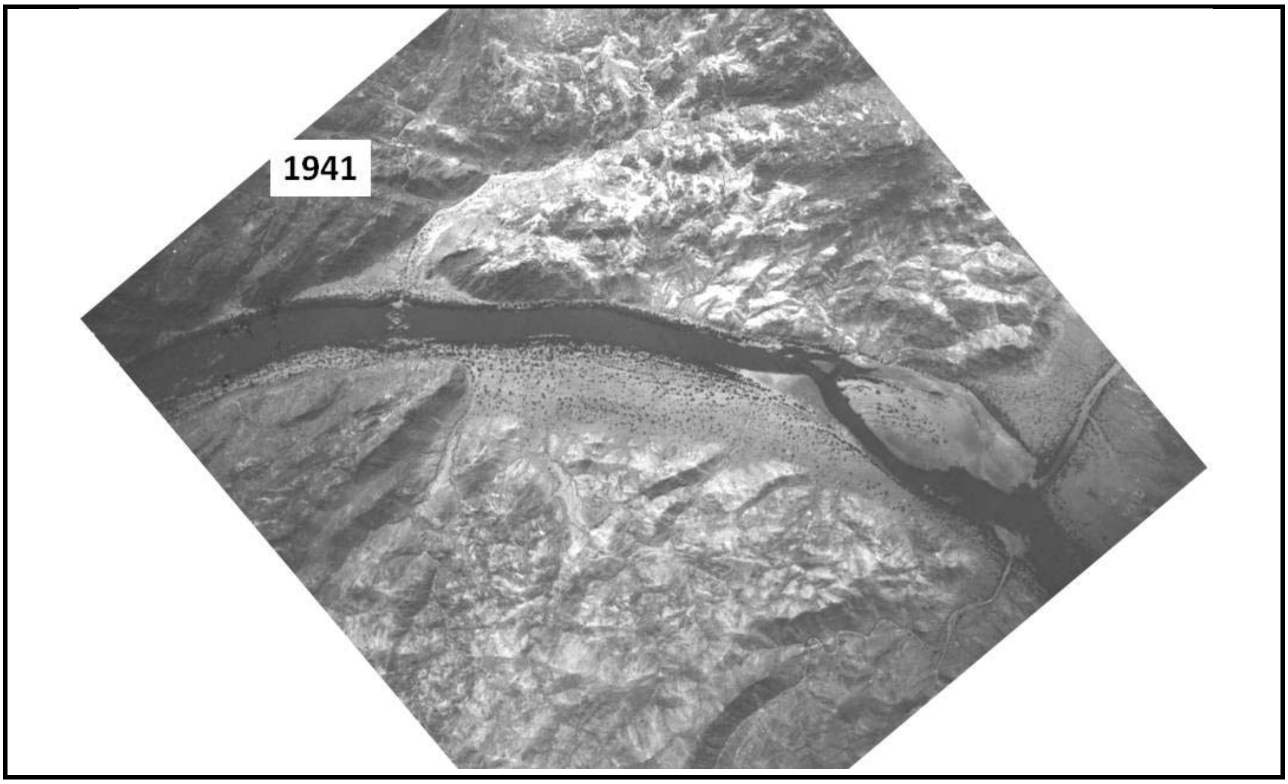
- The site has some bedrock control and therefore is not very sensitive to the impacts of baseflow and small flood changes.

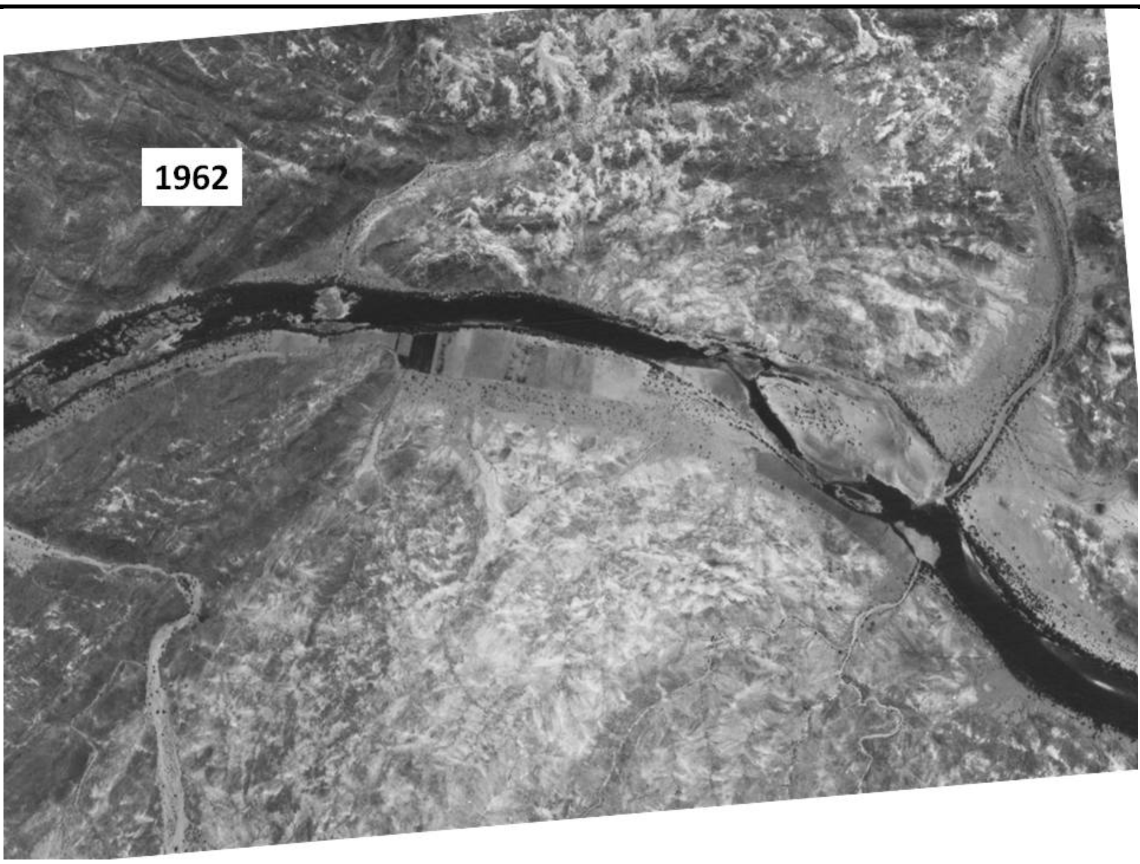
E2.3.5 Trends

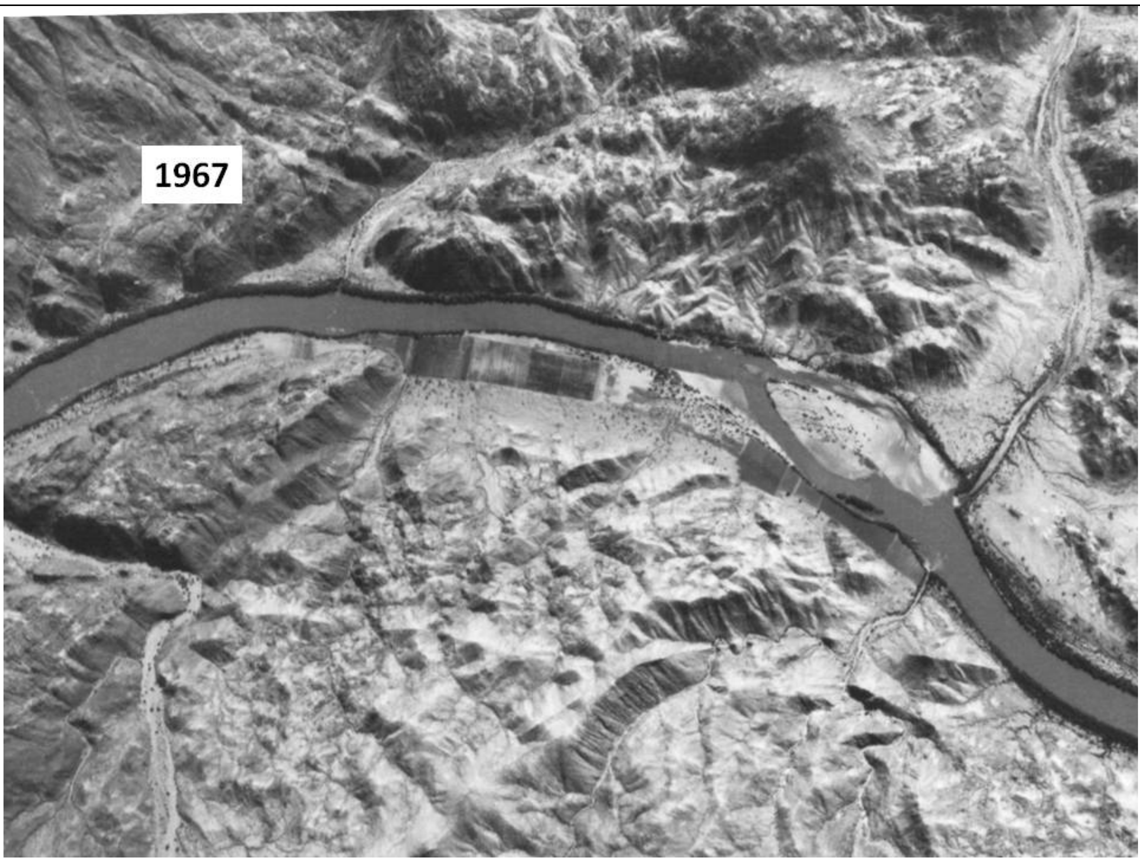
The overall trend for the Geomorphology is stable.

Figure E6 Large cobble bars and small fines deposits are present at EFR O3

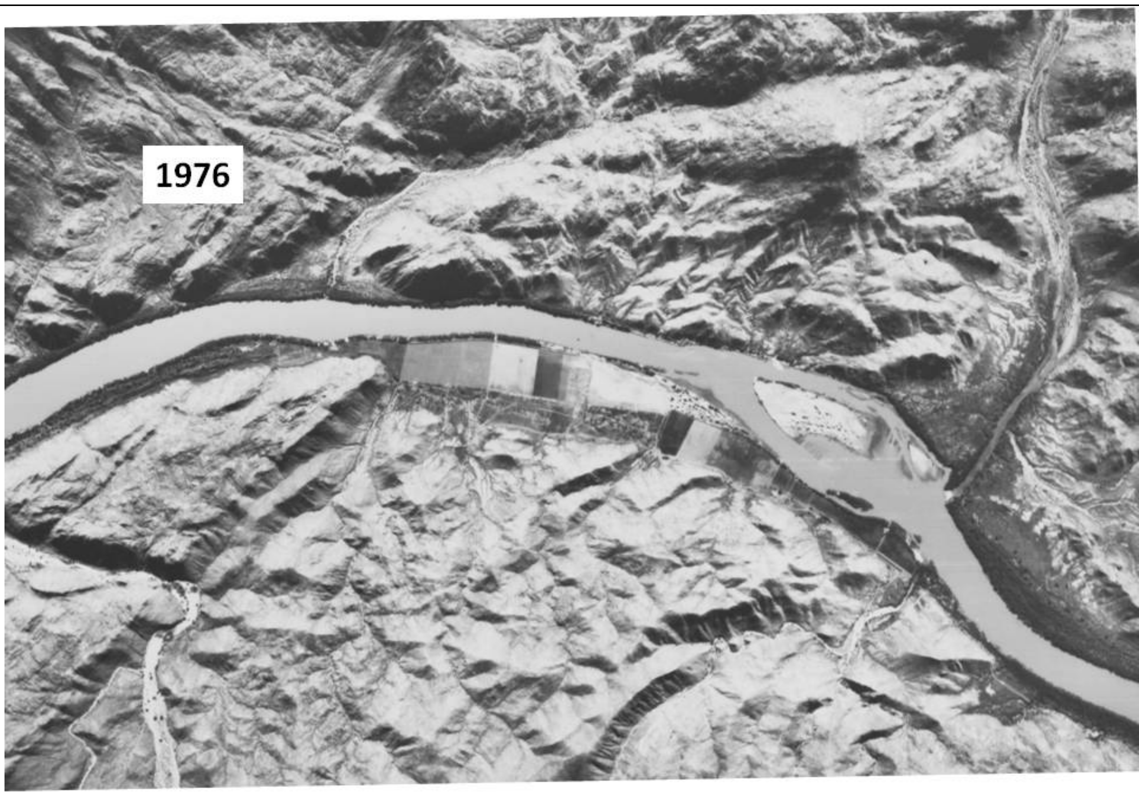
Table E 4 The historical aerial photographic record for EFR O3

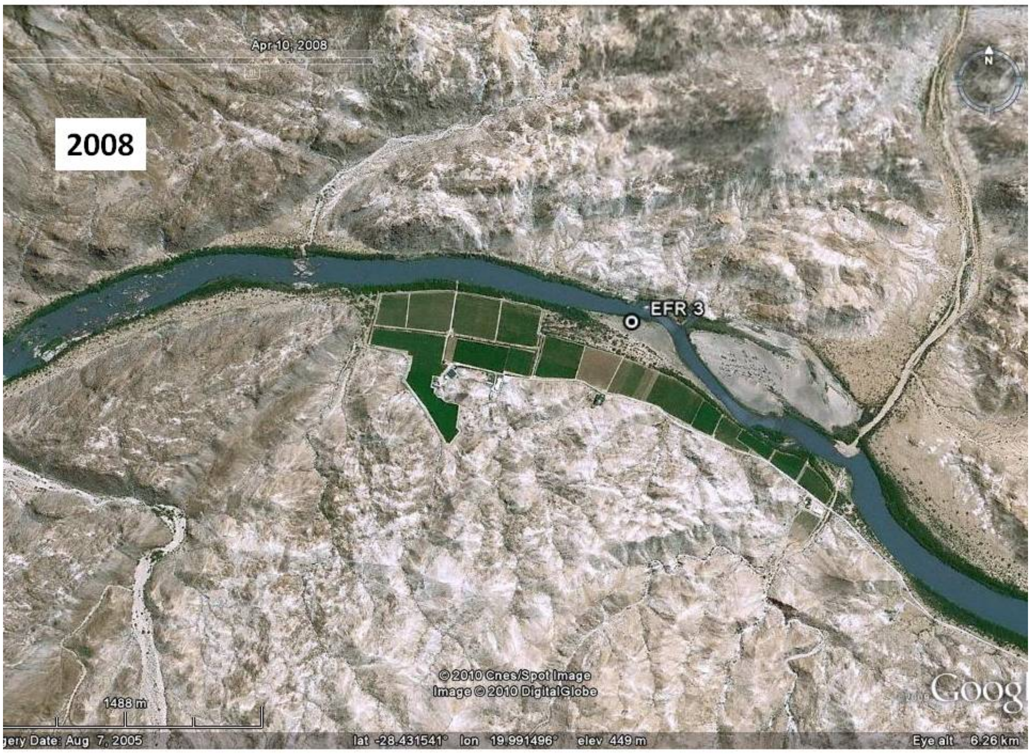



1962


1967


1969


1976



E2.4 EFR O4: VIOOLSDRIFT

E2.4.1 Available data

A historical aerial photographic record dating back to the 1930's was available for this site, as well as anecdotal descriptions of the river reach from the Orange River Reconnaissance Study that was conducted in the early 1900's. These data document gross morphological changes to the site and reach and aid in the Reference State and PES determinations and assessments.

The D8H003 gauge was used to represent flows at the site, since this gauge provides a long discharge record beginning in 1935.

E2.4.2 Reference Condition

The Orange River Reconnaissance Study (1906-1914) yielded annotated maps of the study area for EFR O1 - 4. Around EFR 4, some notes were made about the sediment composition of the bed of the river. Descriptions of the reach (from EFR site 4 to the mouth) noted a variety of sedimentary deposits, from "very muddy banks" (close to the EFR site), to shingly beds (at Vioolsdrift), and then further downstream the Orange is described as having a very sandy bed. Even further downstream around the Richtersveld the Orange is described as "bed very rocky, banks rough and stony".

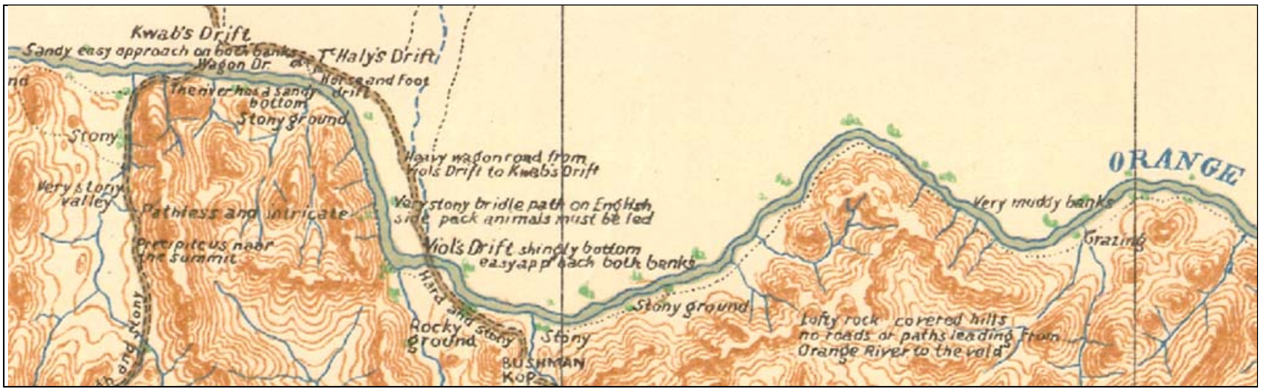


Figure E7 Annotated maps from the Orange River Reconnaissance Study (1906-1914) yielded some useful anecdotal evidence of the morphology of the river in this reach

The banks also are described as well-wooded in places – near the Richtersveld the reach description states that "both banks (are) well wooded with mimosa and bastard ebony", and general notes indicated that an "abundance of firewood (was) to be had all along the Orange River" and that close the mouth "great quantities of debris of trees etc lie on banks".

E2.4.3 Description of the current condition

The historical aerial photographic record indicates that small (bedrock core) bars within this pool rapid/riffle reach are, since the 1980's, becoming slightly more extensive and stable (increasingly vegetated). These may be responding to the very reduced low flows and near absence of moderate and large floods as occur at EFR O2 and O3. The reduced floods and baseflows (MAR is about one third of the virgin flow volumes) decrease the ability of the river to flush out sediment, whilst the surrounding tributaries are adding increasing volumes of sediment to the main channel.

Figure E8 At EFR O4, there is a mix of cobbles, gravels and fine sediment deposits within the bedrock-controlled reach

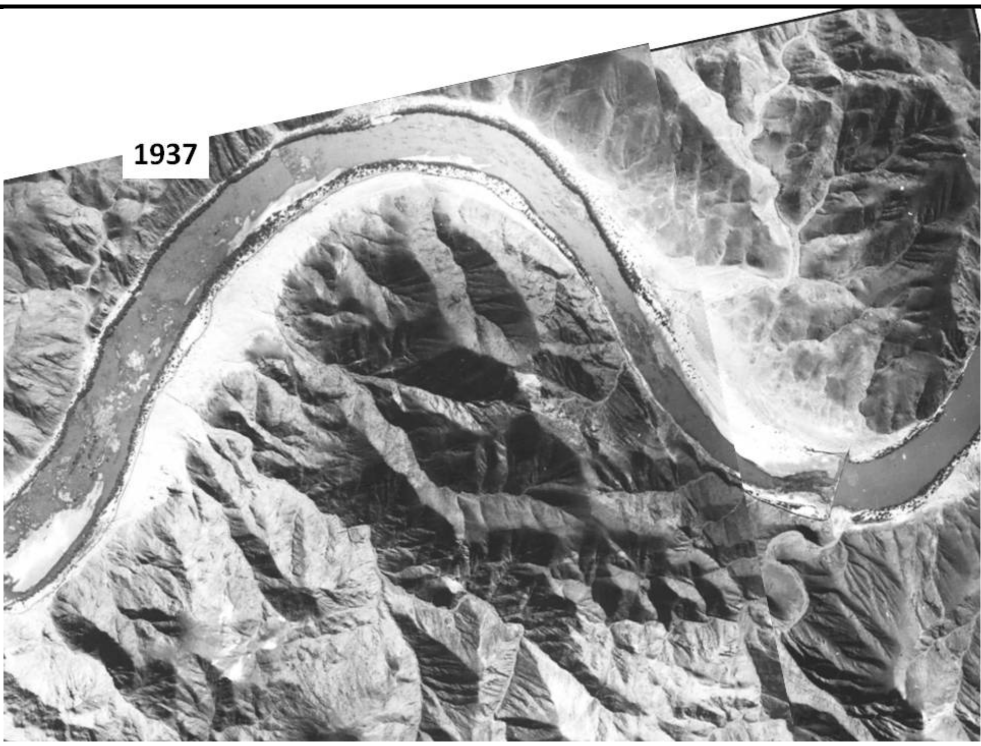
E2.4.4 Present Ecological State Category

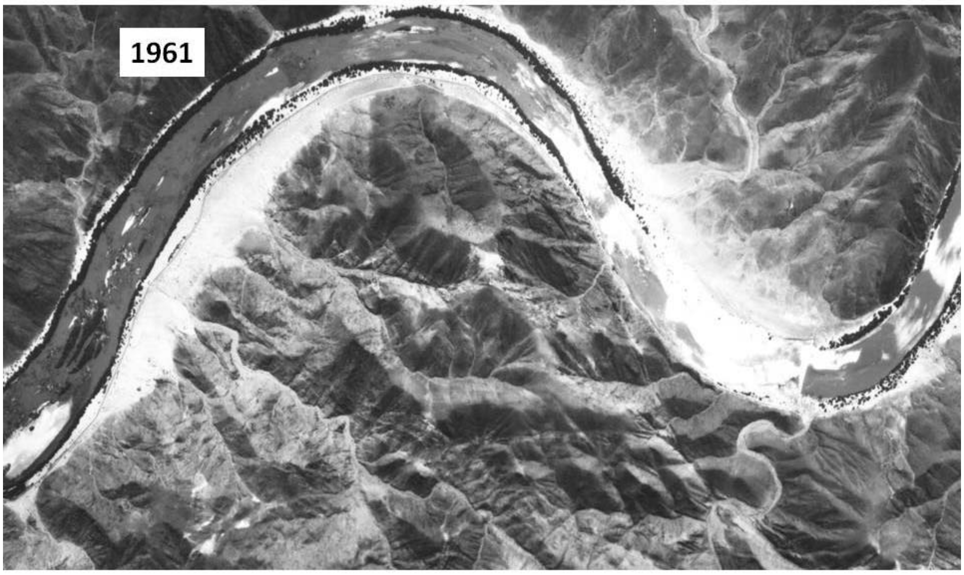
The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES of the Geomorphology is in a C (74%) EC. The reduced sediment loads (since much is trapped in upstream dams) is being increasingly replenished by tributary inputs. The critically reduced flows at the site and lack of moderate and large floods continue to constrain channel and habitat maintenance. The key issue for this site is the loss of floods that scour and maintain the channel bed and bars.

E2.4.5 Trends

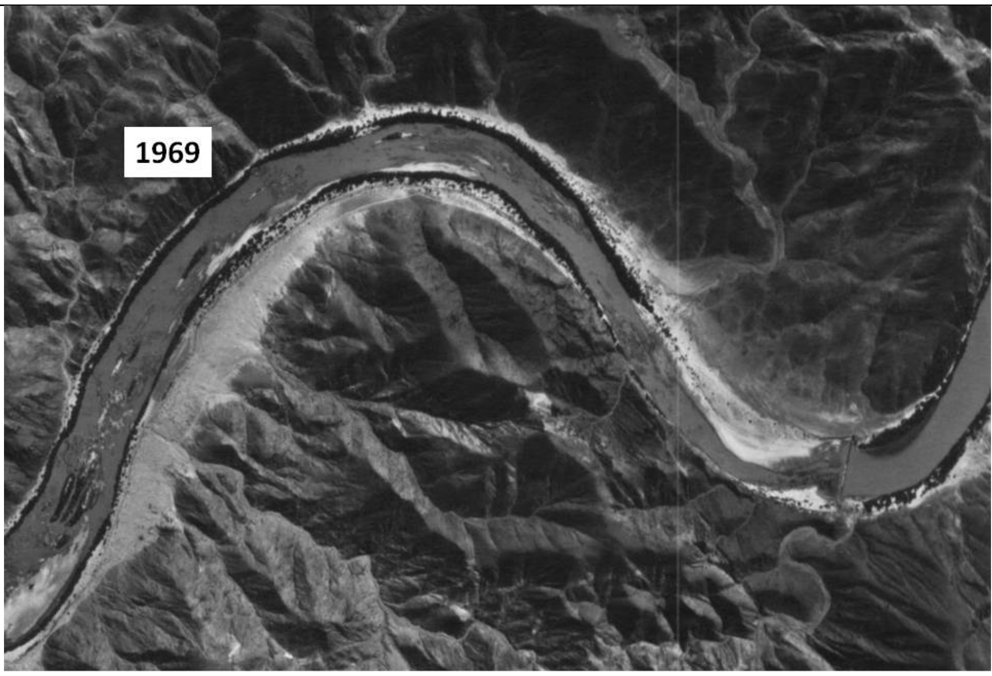
The overall trend for the Geomorphology is stable.

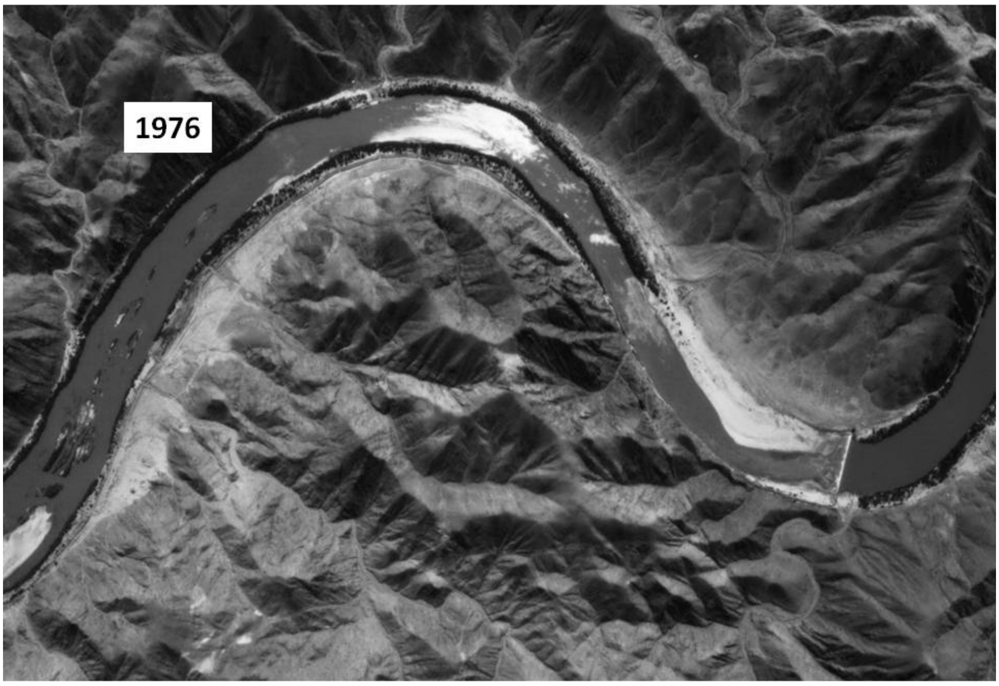
Table E5 The historical aerial photographic record for EFR O4

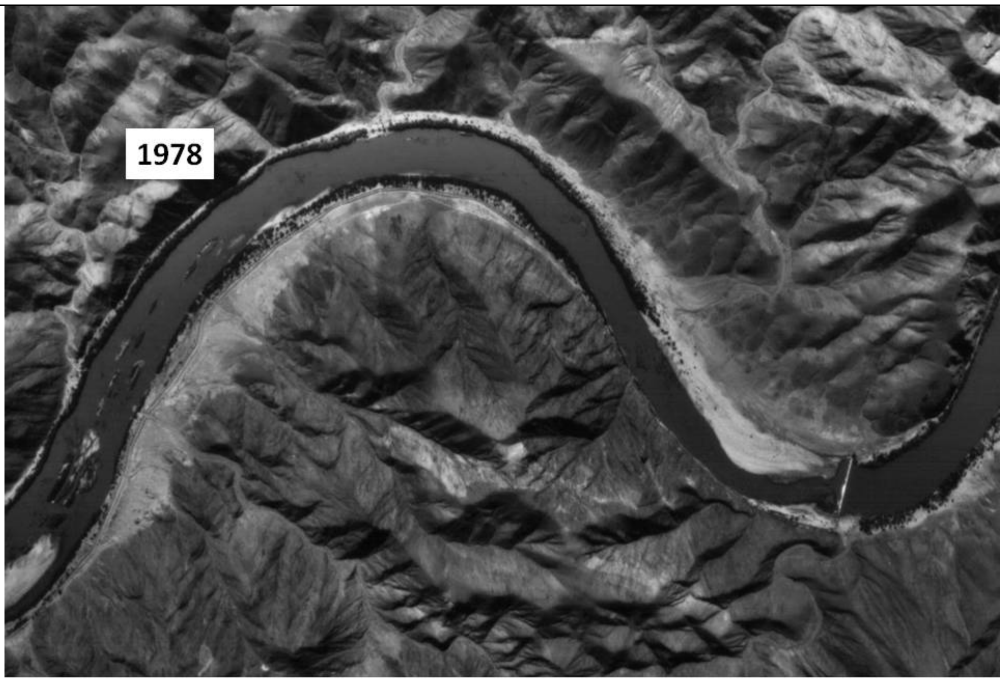


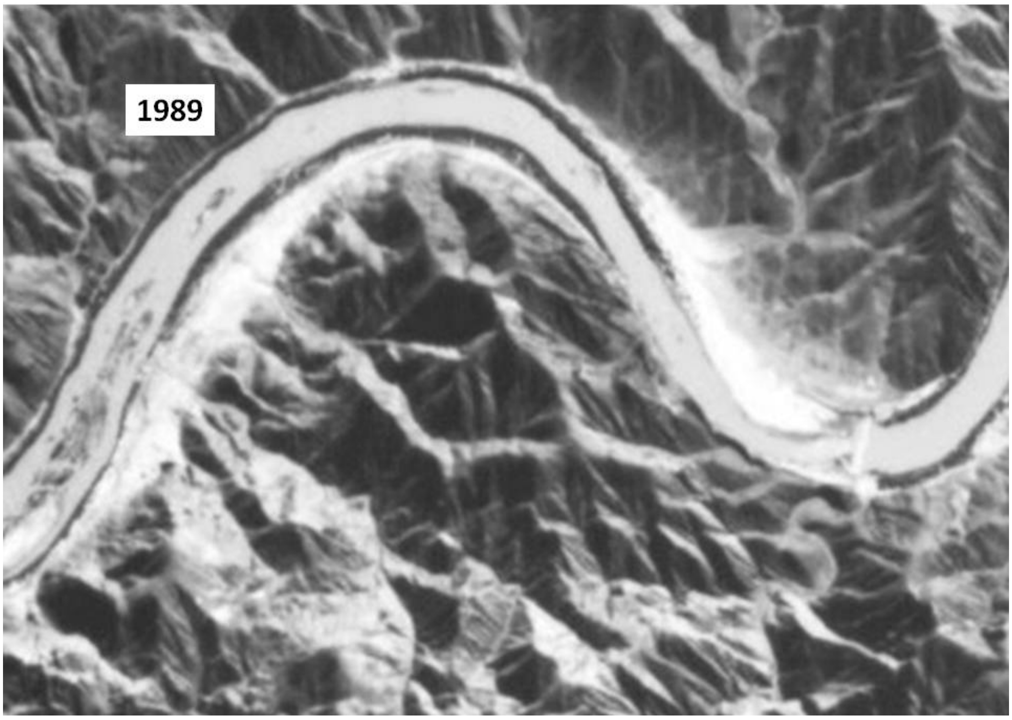



1964


1969


1976


1978



E2.5 EFR C5: UPPER CALEDON RIVER

E2.5.1 Available data

A historical aerial photographic record dating back to the 1960's was available for this site. This documents gross morphological changes to the site. At the site visit, the cut banks indicate the original bed composition and subsequent more recent sediment deposits which have been deposited over this.

The nearest discharge gauge (D2H035) is 60km downstream of the EFR site. This is too far to represent flows at the site (more than 5 times the size of the catchment at the EFR site), making sediment transport modelling impossible with the available data. This presents a major limitation to identifying EFR requirements for geomorphology at this site.

E2.5.2 Reference Condition

Under Reference Condition (100 – 200 years ago), this reach of the river probably was a well defined channel with sand, gravel and cobble bed elements. The banks would have been well-vegetated, although cut banks along bends would be common as it was a net erosional (incising) system.

E2.5.3 Description of the current condition

The river is currently incising into older floodplain pockets. Although there is little change in hydrology from the Reference Conditions, one would expect this headwater-type river to be incising, the rate and extent of incision and bank cutting is likely increased above natural through bank destabilisation caused by high grazing pressure and woody vegetation loss on both banks.

The sediment production in the catchment is very high in comparison to natural. Much of the catchment has been cleared for cultivation, and grazing pressures are high. The steep slopes, poor vegetation cover and intense rainfall events promote erosion. Dongas across the catchment are widespread. Exotic vegetation is, in places, playing some role in stabilising sections of eroding banks and dongas. This high sediment load is reflected in the instream condition of the river. The original bed of the river was probably gravels and cobbles with some sands. These larger bed elements have been smothered by the high sands and fine loads from the eroding lands in the catchment. Some cut banks near the EFR site (Figure E9) indicate up to 2 metres of fine sediment having been deposited over the original cobble beds over only a few flow events. This explains the somewhat “messy” structure of the banks and extensive eroding/cut banks – this river is eroding in to recent lateral deposits that were rapidly deposited over the original cobble marginal and lower riparian zones. Bank structure is thus messy and terraces poorly developed because it is likely that large scale morphological changes occur with single large flow (flood) events due to the very high sediment loads available for reworking.

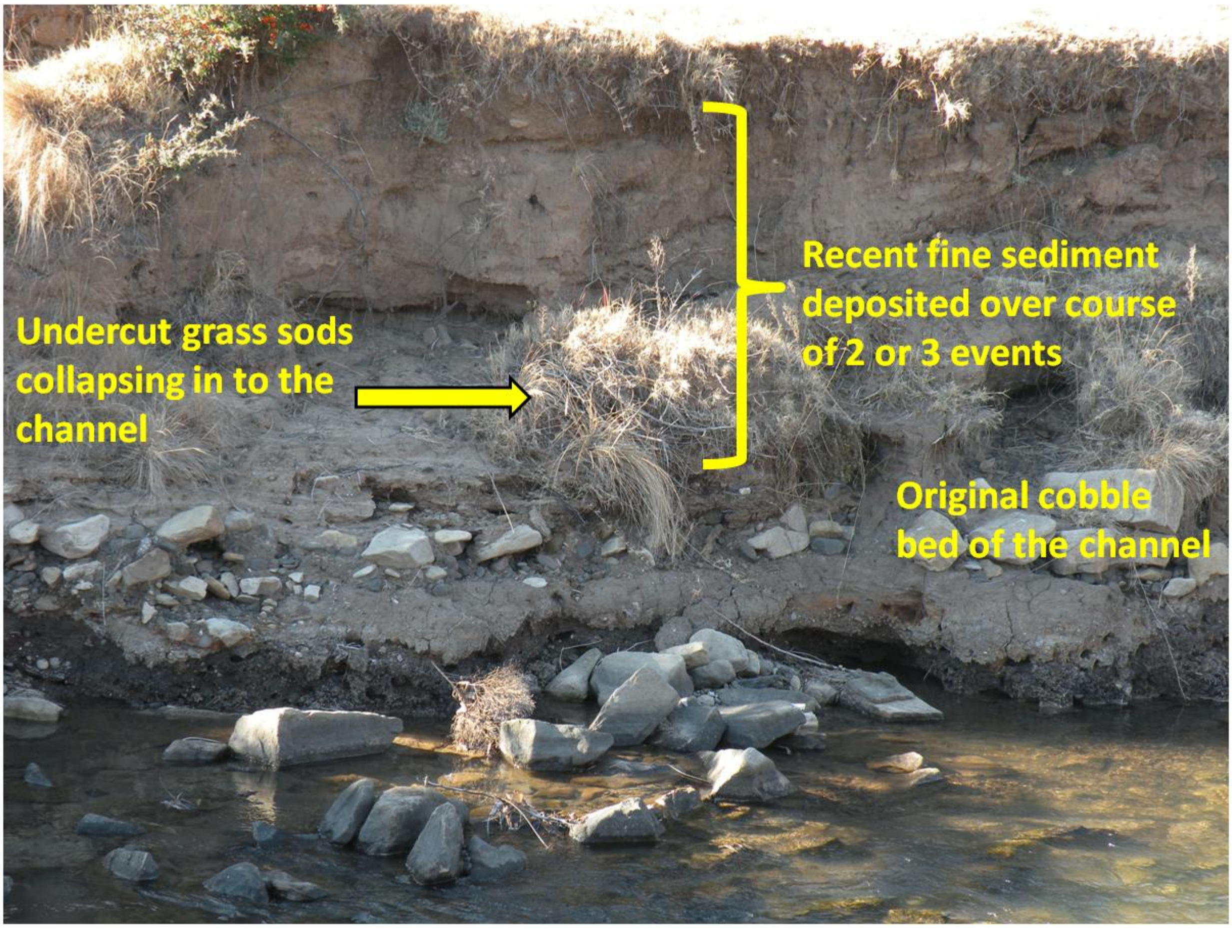


Figure E9 Sediments exposed on a cut bank.

The smothering of gravels and cobbles has converted extensive sections of the reach to a sandbed channel (Figure E10). The historical aerial photographic record (shown below) record a progressive loss of large woody vegetation (trees) along the banks of the main river in this reach. The removal of trees may be the result of bank erosion, heavy grazing pressures and firewood useage. The loss of woody vegetation may have further increased the bank destabilisation evident at the site, in turn further destabilised by livestock - grazing pressure is high.

E2.5.4 Present Ecological State Category

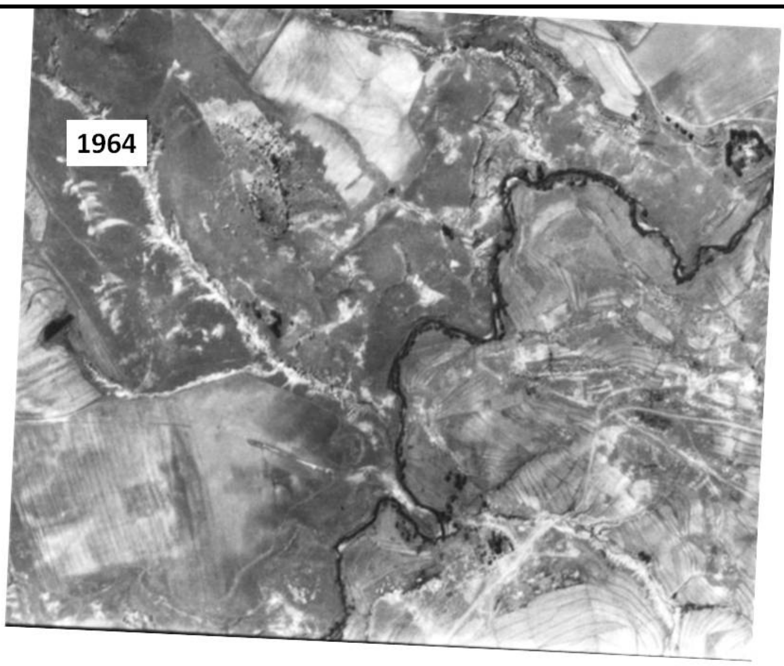
The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES of the Geomorphology is 68% and in a C (moderately modified) ecological category. This is primarily attributed to the high sediment loads (sands and fines) being introduced from the upstream hillslopes and associated drainage lines, and destabilisation of the banks along the channel. These have caused large changes to the condition of the instream habitats through reduction in cobble and gravel in-channel habitats, and loss of marginal vegetation. The instream biotic indicators demonstrate these problems of increased sedimentation in the active channel – excess fine sediments are the primary cause of poor ecological condition for both the fish and instream invertebrates.

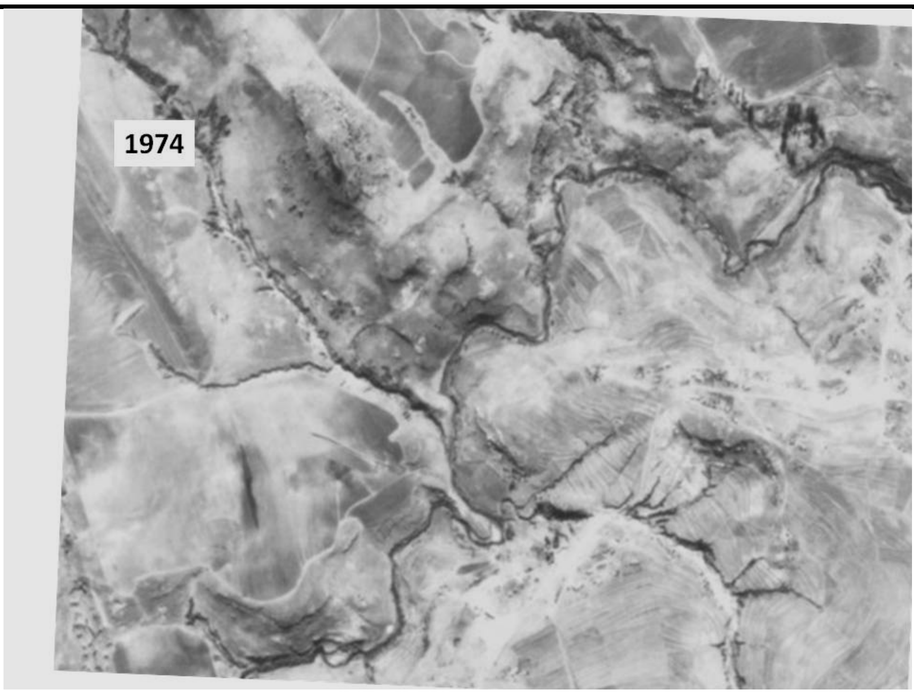
Figure E10 The increased fine sediments in the channel have converted large sections of the reach to a sandbed channel as the sands smother the underlying gravels and cobbles

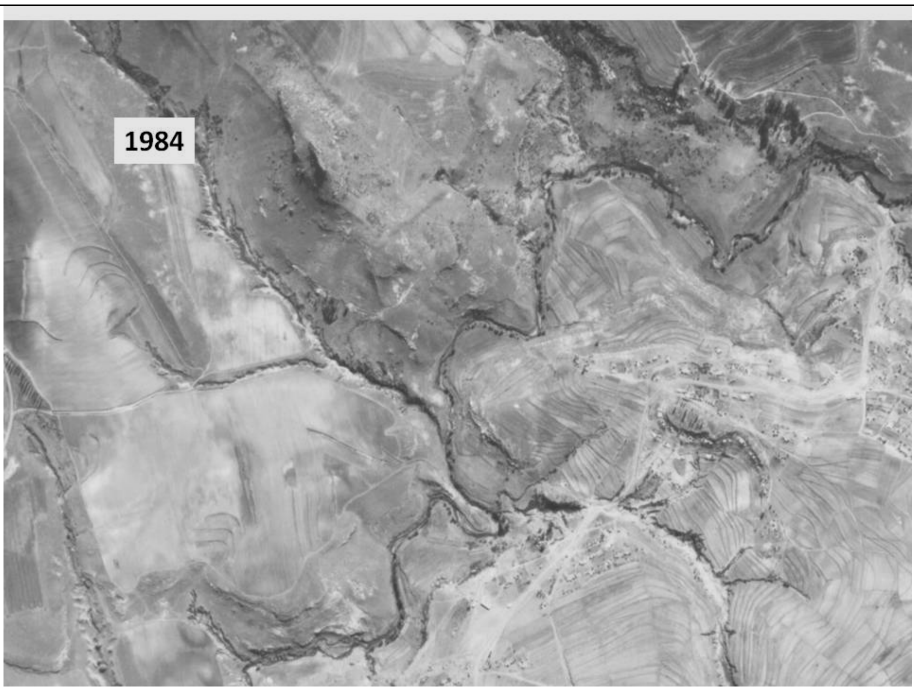
E2.5.5 Trends

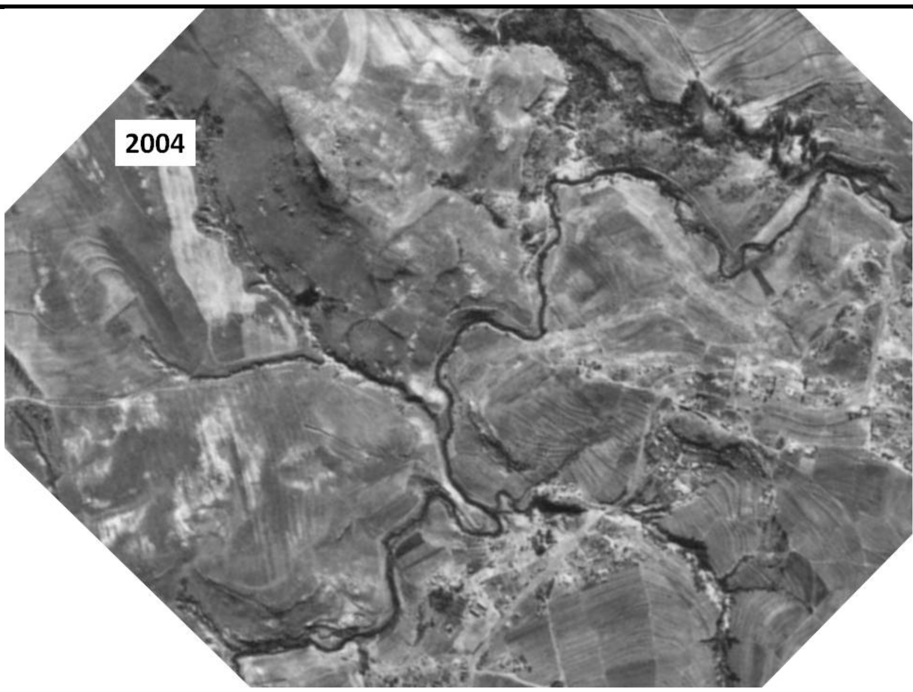
The overall trend for the Geomorphology is negative. This is because sediment yields from the catchment remain high (lands under cultivation and donga erosion are expanding; bank destabilisation of the channel is ongoing) so it is likely that the condition of the river channel will continue to deteriorate as more and more of the original banks are eroded and cobble/gravel elements within the channel become progressively smothered.

Table E6 The historical aerial photographic record for EFR C5




1974


1984


2004


2010
EWR5 CALEDON
© 2010 Cnes/Spot Image
Google
661 m
lat -28.648545° lon 28.387817° elev 1644 m
Eye alt 5.66 km

E2.6 EFR C6: LOWER CALEDON

E2.6.1 Available data

A relatively long historical aerial photographic record (dating back to the 1940's) was available for this site. This documents gross morphological changes to the site. The nearest discharge gauge (D2H033) is located upstream of the site at Welbedacht Dam.

E2.6.2 Reference Condition

Under Reference Condition (100 – 200 years ago), this reach of the river probably was a well defined braided channel with sand and gravel bed. The banks would have been relatively well-vegetated, with poorly vegetated more dynamic low-lying active channel braid and lateral bars.

E2.6.3 Description of the current condition

As discussed at EFR C5, the sediment load from this catchment is naturally high, but is elevated due to clearing for cultivation on soils that are naturally easily erodible. Although this is a bedrock rapid section, fines dominate the bed. Recent floods have deposited several metres of sediment along the banks. In the faster flowing sections of the bedrock rapid section of the channel there are some gravels and cobbles on the bed, but these are all embedded by fines.

In addition, this site appears, at VERY high flood flows, to be in the backup of the confluence with the Orange River (confluence is 30 km downstream); possibly even in the backup of the Gariep Dam. This is suggested by the:

- Sediment deposits high up the bank which have clearly been deposited at extremely low velocities (the fine grasses within the deposits are still standing straight up).
- How the entire bed of the channel seems to have been covered by sediment and then subsequently cut back down as the flows dropped and backup effect is removed, and
- Aerial photographs (below) indicate the stabilisation of the point bar upstream of the site (changing from poorly vegetated in the 1940's to dominated by woody vegetation currently). This pattern of change supports the assumption that the high elevation sedimentary deposits are becoming increasingly stabilised.

Given the increased sediment load from the catchment; the backup effects at the site during very large floods which promotes enhanced deposition; and the annual bottom releases from the upstream Welbedacht Dam (release of sediment slug during low flow periods to scour the dam), it is expected that this site has a much higher fines component, and more stable sediment deposits, than would have occurred naturally. In addition, the expected reduced velocities during very high floods may now be too low to scour the bed and activate the gravels.

The same aerial photographs do however show that the gross morphology of the low flow channels is relatively stable, and this is because at low and moderate flows the backup impacts are not in place, so erosion and scour of these low flow channels still occur despite the episodic smothering during high floods.

Figure E11 The bedrock riffle at the site is expected to be smothered by fines during very high flood flows due to backup impacts; but this feature is re-exposed during the receding limb of the floods when the backup effect is removed and velocities increase, enabling scour.

E2.6.4 Present Ecological State Category

Based on the above, the Geomorphology was assessed to be in a C/D EC. This is primarily attributed to the high sediment loads (sands and fines) being introduced from the eroding upstream hillslopes and associated drainage lines, the bottom release sediment flushes (from Welbedacht) during low flows and the backup impacts at this site. These impacts have caused sedimentation of the lower riparian zone and smothering of the instream habitats through reduction in deep areas and gravels.

E2.6.5 Trends

The overall trend for the Geomorphology is stable, as it is believed that the backup effects are not likely to play a further major role in degrading the site because low and moderate flows still scour the bed.

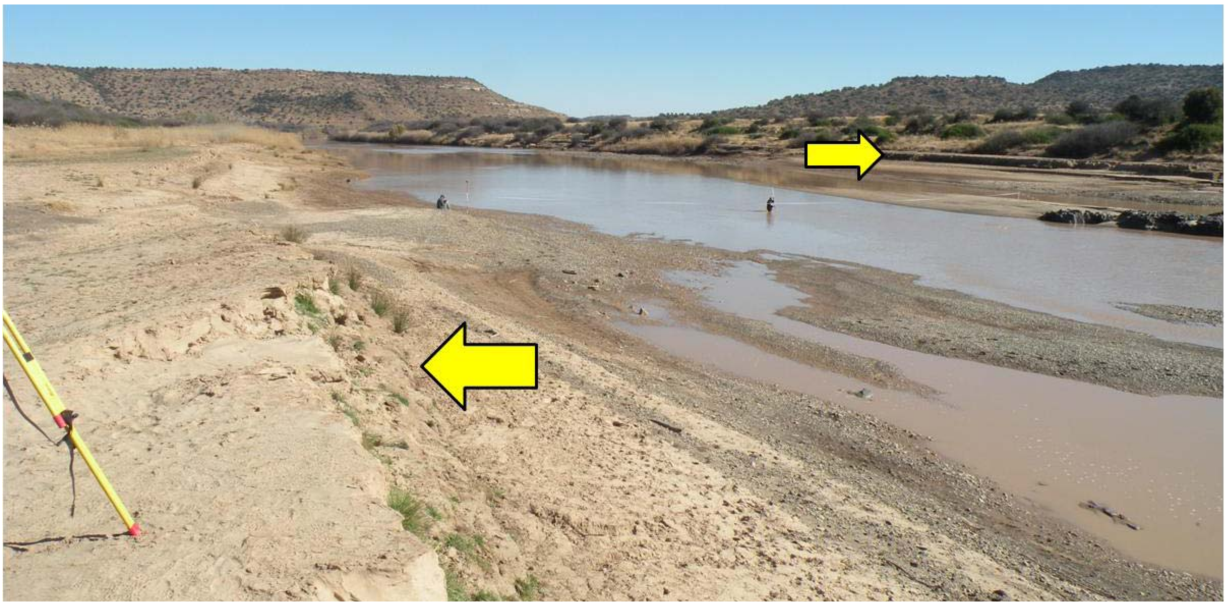
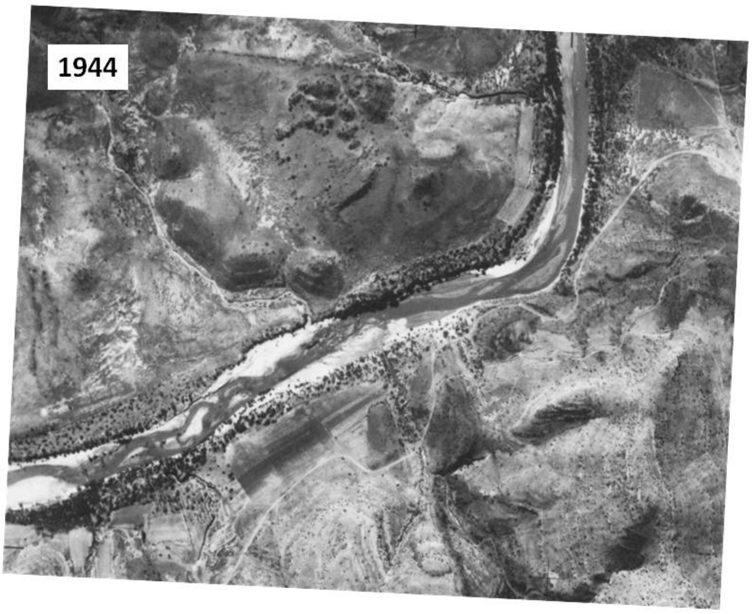
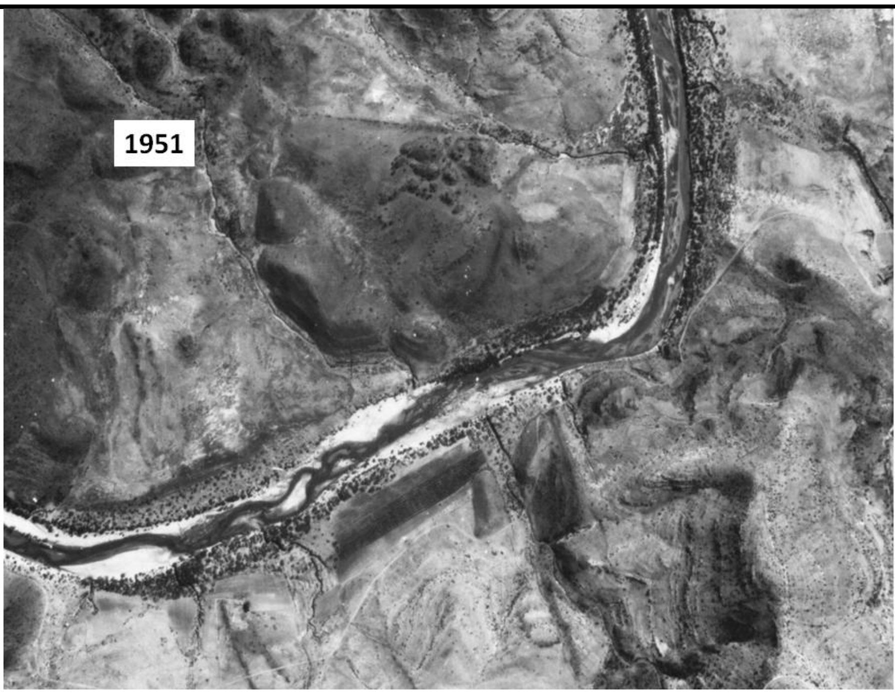


Figure E12 Thick sand/silt drapes deposited along both banks during high flood flows

Table E7 The historical aerial photographic record for EFR C6




1951


1969


1974


2010
EWR6 CALED
© 2010 Tele Atlas
Image © 2010 DigitalGlobe
© 2010 Europa Technologies
783 m
Feb 14, 2008 - Mar 29, 2008
lat -30.451882° lon 26.271697° elev 0 m
Eye alt 2.71 km

E2.7 EFR K7: KRAAI RIVER

E2.7.1 Available data

A historical aerial photographic record dating back to the 1960's was available for this site. This documents gross morphological changes to the site.

The nearest discharge gauge (D1H011) is at the EFR site. The information provided by the hydrologist suggests that medium to high flows may be underestimated at this gauge due to submergence.

E2.7.2 Reference Condition

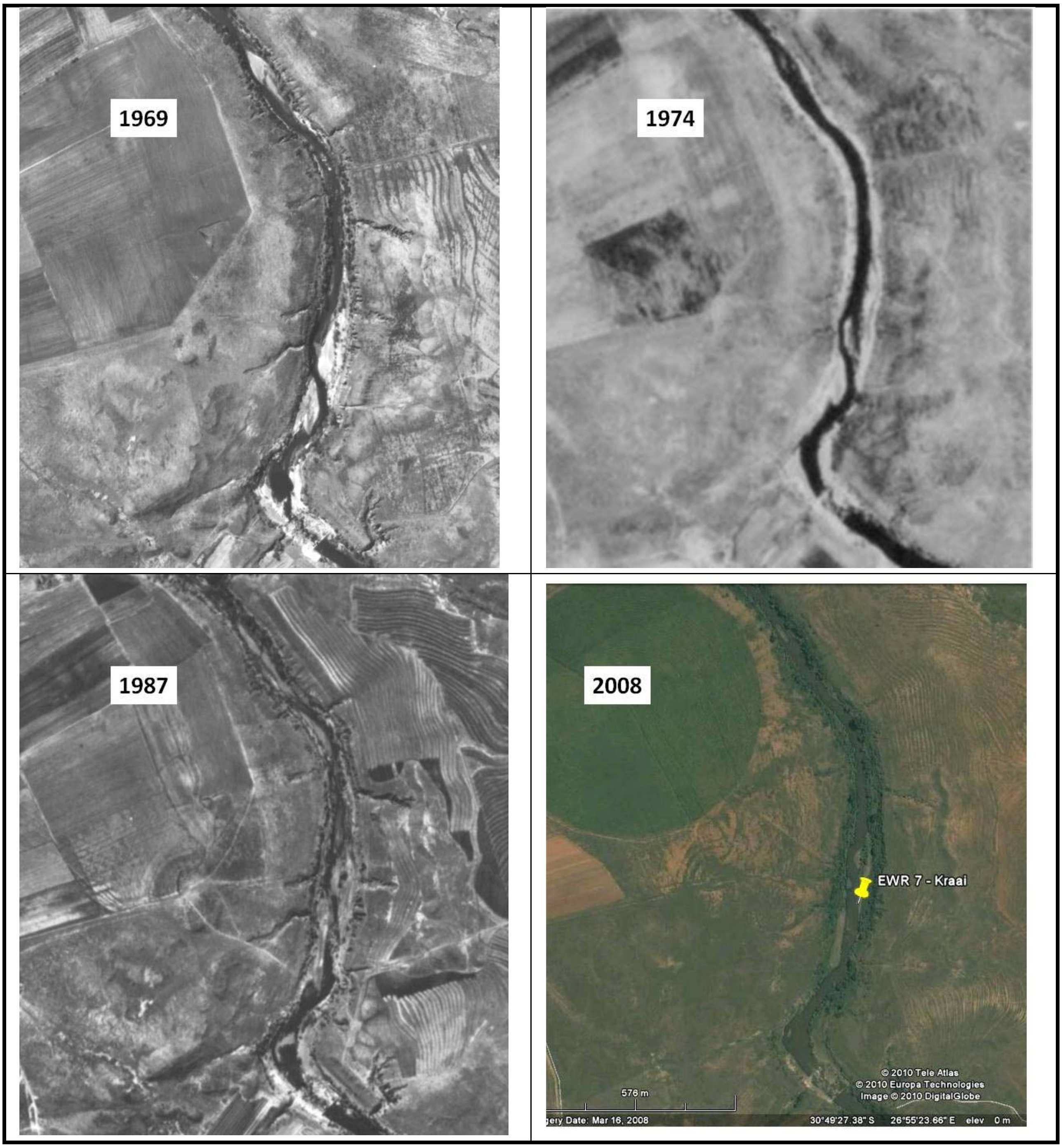
Under Reference Conditions, this reach of the river probably was a well defined pool-riffle system with a gravel/cobble bed. The lateral and braided bars would be highly mobile and cobbles and gravels would not be embedded, and the bars probably not vegetated. A series of terraces in the riparian zone could be expected to be associated with infrequent floods.

E2.7.3 Description of the current condition

The aerial photographic record shows no directional change in the morphology. Although in the 2008 Google Earth image the area of bars appear slightly reduced, this image was taken in March 2008 and would be higher flow than the older historical aerial photos. This means that the apparent reduced area of bars is due to a higher water level and not erosion of these features. Morphology overall thus appears to be stable. Upper riparian vegetation has become more dense and this is believed to represent the high density of invasive exotic vegetation seen at the site.

Irrigated and rain-fed agriculture in the catchment has had some impact on the river. Baseflows have been slightly reduced and zero flows appear to occur fairly often under present day, but would have expected only very occasionally under reference conditions. Small floods may have been slight reduced as a result of farm dams. The MAR is slightly reduced from natural due to abstraction and the impacts of small farm dams.

Table E8 The historical aerial photographic record for EFR K7



E2.7.4 Present Ecological State Category

The PES Ecological Category was assessed using the Geomorphological Assessment Index (Level IV) (Rowntree and du Preez, in prep). This indicated that the PES of the Geomorphology is in an A/B (90.6%) EC. The PES of the Geomorphology is thus only slightly modified from natural. Although baseflows are slightly reduced and there are small farm dams and weirs upstream, and extensive agriculture in the catchment, these have not had a measurable impact on the geomorphology at the site. High flows and floods are relatively unimpacted by the changes in the catchment, and the geomorphology at this site – dominated by larger cobble/gravel bed elements – is not sensitive to the small changes in baseflows.

E2.7.5 Trends

The overall trend for the Geomorphology is stable.

E2.8 EFR M8: MOLOPO WETLAND

E2.8.1 Available data

A historical aerial photographic record dating back to the 1940's was available for this site. This documents gross morphological changes to the site. The aerial photographs were used in combination with previous assessments of the lower wetland areas close to Mafikeng, and other assessments conducted in similar wetlands in the area, to define the Reference Conditions.

E2.8.2 Reference Condition

This wetland would have been a weakly channelled, permanent wetland system, changing to more seasonally saturated wetland towards Mafikeng. *Phragmites* would have been completely dominant in the permanent wetland areas; and this would have changed to a mix of reeds, *Typha*, sedges and hygrophilous grasslands towards the outer margins and also downstream in the more seasonal areas.

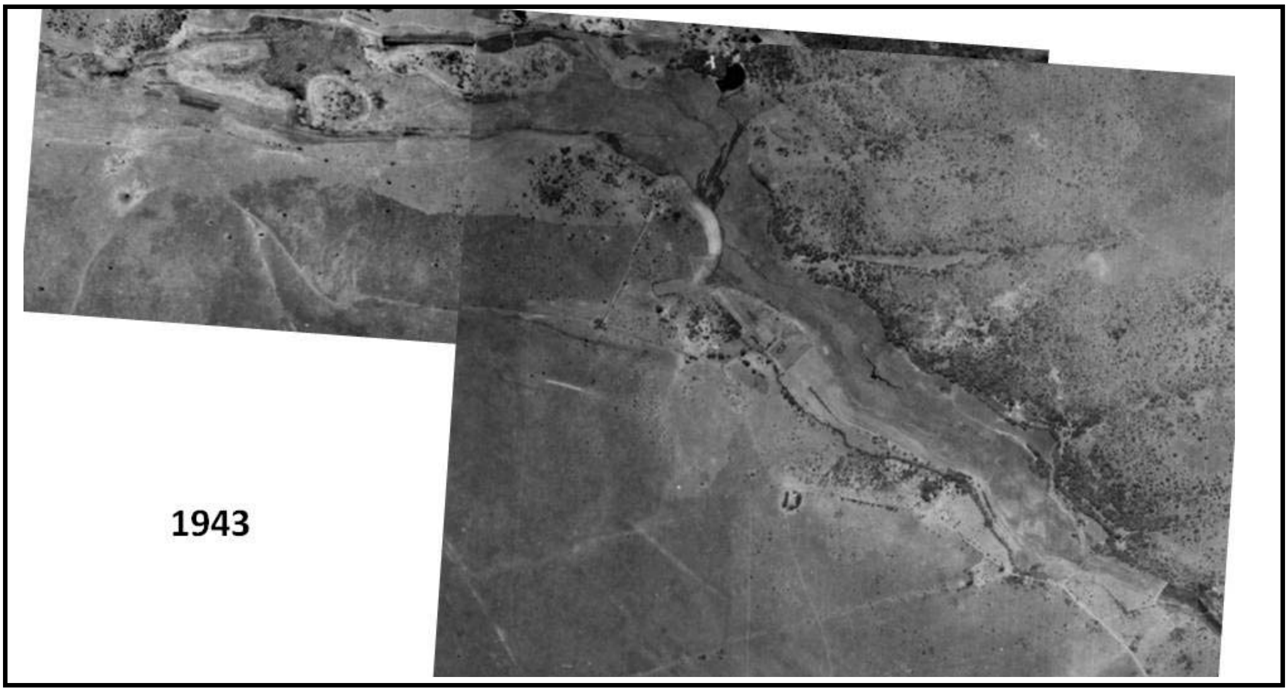
E2.8.3 Description of the current condition

The Molopo wetland is a groundwater dependent wetland system. Almost all inflows arise from the eyes (springs) that emerge from the underlying dolomitic geology. Much of this flow has been diverted by a weir close to the source such that the flows within the wetland are very reduced from the Reference Condition, and consequently the area of wetland which is maintained as permanently or seasonally wet is far reduced from the natural state. Desiccation of the wetland has allowed terrestrial grasses to encroach, burning of peats and an overall reduction in wetland area. It is also possible that diffuse abstractions from the aquifer generally (i.e. groundwater pumping in the dolomitic compartment) may also have reduced yield at the eyes; thus further reducing flows.

Small weirs, dams, road crossings and drains have also had a direct impact on the water distribution across the wetland surface. Since the 1970's, one or a combination of factors - raising of a road crossing, excavation of the peats for boating and fishing areas, and possible spraying of the reeds to kill them – has caused open water areas to develop in one section of the wetland (see Figure below). Downstream of this the reduced flows in the wetland, and trapping of flows behind the structures, has caused extensive desiccation and terrestrialisation of the wetland. Canalisation of sections of the wetland has also prevented water flowing diffusely across the valley bottom, further reducing the area of wetting.

Figure E13 The road crossing has created an impoundment upstream. This has artificially increased the water level, and excavation in the wetland to create fishing and boating areas have created further disturbances in this area. Die off of the reeds has occurred between 1975 (right image) and 2008 (left image)

Table E9 The historical aerial photographic record for EFR M8




1975


1985

E2.8.4 Present Ecological State Category

This reach of the Molopo is a wetland, and the application of the Geomorphological Assessment Index (GAI) is not appropriate because the GAI is designed to determine the Present Ecological State (PES) of the geomorphology of river reaches. Instead, a tool for rapidly assessing the PES of wetlands, the Wetland Index of Habitat Integrity (DWAF, 2007) was applied to the reach to determine the PES of this valley bottom wetland unit. The PES was determined for the Management Resource Unit (MRU A), and for the small area at the EFR site (Table E10). Both were assessed because, as due primarily to very localised backup impacts from a downstream elevated road crossing, the EFR site is not representative of the condition of the MRU. The scores for the MRU – overall in a C category - are ameliorated by better condition sections up- and downstream of the EFR site (which is in a D category).

Table E10 Wetland Index of Habitat Integrity results for the larger MRU (A) and the small EFR site (EFR 8) nested within the MRU

Component	MRU A	EFR site 8
Hydrology	C/D	D/E
Geomorphology	A/B	B
Water Quality	B	B
Vegetation Alteration	C	C/D
OVERALL ECOSTATUS	**C**	**D**

E2.8.5 Present Ecological State Category: MRU A

The PES assessment for MRU A indicated that the site is in a C (moderately modified) Ecological Category. The reasons for the current condition are:

- Very reduced inflows into the wetland due to abstraction at the eye.
- Increasing the water depth and drowning out of natural vegetation through the creation of dams/impoundments, road crossings and weirs and the associated backup effects of these structures, as well as excavation of the wetland for fishing and boating areas.
- The reduced inflows and trapping of flows in impoundments has overall reduced the extent of the wetland that is wetted (i.e. reduced area of permanently and seasonally saturated soils).

- Ongoing spraying of reeds to control *Quelia* populations has caused extensive die-off of reeds and invasion by more weedy species.
- Creation of artificial deep, open water areas has changed the natural distribution of habitats and promoted establishment of more weedy species in the wetland.

E2.8.6 Present Ecological State Category: EFR M8

The PES assessment for EFR M8 indicated that the site is in a D (highly modified) Ecological Category. The reason that this site is worse than the MRU within which is it nested is that negative impacts are concentrated at this site.

- Although the EFR site is similarly affected by the reduced inflows (due to abstraction at the eye), the backup impacts from the road crossing has caused deep water sections to develop which prevents natural vegetation patterns from developing.
- Spraying or other means for killing reeds is concentrated in this section of the wetland, further reducing natural vegetation.
- The high disturbance levels have enabled more weedy (albeit indigenous) vegetation to establish in the wetland.

E2.8.7 Trends

The overall trend for the wetland is stable, but this assumes that the current flows will be maintained.

E3 DETERMINING FLOW REQUIREMENTS

Flow requirements for the maintenance of channel form, or geomorphology, can generally be determined using one, or a combination, of two possible approaches. The first relies on specialist knowledge and experience to identify alluvial morphological cues at the site and within the reach which are associated with regular flooding return frequencies (such as active, seasonal and ephemeral paired benches and terraces). The second approach uses the catchment hydrology and site-specific hydraulic characteristics to model the long term potential sediment movement within the river to identify so-called geomorphologically effective discharges. These are ranges of flows which are responsible for a disproportionately large amount of the long term sediment transport (geomorphic work) which is happening at the site.

E3.1 MORPHOLOGICAL CUES

The rivers in this study are generally not strongly alluvial depositional systems Most sites have at best poorly defined benches within their incised macro-channels; the channels themselves often flowing along the underlying geology of the area. The notable exception of these characteristics is at EFR 8 – the Molopo wetland system. Morphological cues work best in alluvial, stable or net depositional river reaches. Most of the Orange River is net erosional (incising) and thus does not lend itself to a morphological cue approach to identifying ecologically significant flows for geomorphology.

E3.2 SEDIMENT TRANSPORT MODELLING

The form (morphology) of a river channel is dependent on the interaction between the supply of sediment from its catchment, and the ability, or capacity, of that section of the river to transport the sediment it is supplied with. The ability of the river to move sediment is referred to as its sediment transport capacity. Sediment supply and sediment transport capacity interact such that:

- Where sediment supply is less than the sediment transport capacity, there is an excess of erosive energy, resulting in net erosion, causing the river channel to erode its bed/banks and incise; but
- Where sediment supply is greater than sediment transport capacity, there is an excess of sediment, resulting in net deposition and the development of an aggrading river/floodplain environment.

The interactions described above are generally considered over very long timescales. Over shorter timescales, which are of more interest to river managers (years and decades in southern Africa), studies in eastern southern African rivers have demonstrated that rivers experience periods of metastability or quasi-stability interrupted by periods of rapid change (Carter and Rogers, 1995; Rountree *et al.*, 2000; Rountree and Rogers, 2004; Parsons *et al.*, in press). During these timescales, it is the discharge of water and sediment supply that determines channel form. Where changes in these driving factors occur, the channel form will adjust in sympathy with the imposed change. This is of significance as the channel form provides the physical habitat for riverine biota.

E3.3 GEOMORPHOLOGICALLY EFFECTIVE FLOWS

Geomorphologically effective flows are those discharges that, over the longer term, are responsible for transporting disproportionately larger proportions of the sediment load (relative to their duration). These are essentially the flows that do the most “work” in determining the sediment transport capacity of the channel, and therefore influencing its form.

The calculation of these flows is essentially the sediment transport potential of a particular flow event, multiplied by its duration, which yields its potential contribution to the sediment transport of the system in the long term. The theoretical position taken in these methods is that two sets of discharges are significant in maintaining channel form in southern African rivers:

1) A set of geomorphologically effective discharges in the 5-0.1% range on the 1-day daily flow duration curve, which transport a disproportionately large volume of the sediment in the longer term, and
2) Larger ‘re-set’ flood events such as the flood events of 2000, which can reshape the channel and remove vegetation from the banks and floodplain.

The theoretical basis for these assumptions is presented in Dollar & Rowntree (2003). These methodologies have been used in various ecological flow assessment studies in South Africa (e.g. on the Thukela, Elands, Letaba, Waterval, Vaal and Inkomati Rivers), Mozambique (e.g. the lower Zambezi and Elephantes Rivers), Sudan (Nile River) and Namibia (Cunene River). Whilst it is possible to manage flows up to the 5 to 0.1% range of the flow duration curve, the large “re-set” events are not manageable events. The focus of flow requirement assessments is therefore focussed on the 5 to 0.1% range of flows.

E3.4 METHODOLOGY

The methods employed to determine geomorphologically effective flows for each of the sites are described below.

Observed daily flows at (or scaled to) the EFR site, together with the regional slope, stage/discharge rating curves of the cross-section (provided by the hydraulician) and sediment characteristics for the site were used to model potential bed material transport at each site under the recent (over the observed flow record) flow conditions, using total load equations (Yang, 1973) to determine the effectiveness of discharges. This modelling technique assumes:

1) The bed material sampled at the site is representative of the supply of bed material to the channel (hence potential bed material load as opposed to bed load).
2) Bed material sampling can be averaged at each EFR site and used to represent the cross-section.
3) The supply of bed material to each EFR site is based on the existing bed material and its size distribution, and is available for transport at all discharges; and that
4) Average conditions can be used.

The sediment load of the Orange and main tributaries are generally bedload and suspended load system (with the noteable exception of the Molopo River). Maintenance of the bed habitats is important for biota. In this study we focussed on the mobile component of the bed material at each site (since many sites are located on atypical bedrock riffle areas, and most of the large boulders and cobbles are likely to be insitu weathered material rather than fluvially transported sediment, as evidenced by the angular nature of these larger rocks). The component of the sediment load focussed on for this study, for maintaining in-channel habitats, are compatible with the model assumptions. A full, detailed description of the technique can be found in Dollar & Rowntree (2003). This method was employed at EFR O2 – 4, C5 – 6 and K7 where sufficient hydrological data were available and bedload is dominant. The specific data available for each site and implications for confidence of the results are discussed in the main report. No EFR assessment was undertaken at EFR O1, and the method was not appropriate for the determination of flow requirements at EFR 8 since this site is a wetland.

E3.5 SEDIMENT TRANSPORT RESULTS

E3.5.1 EFR O2

At EFR O2, a very long flow record enabled us to separate out a "near natural" record (from 1932 to 1968 – prior to the operation of any large dams) and a flow record relative of more recent flow conditions (essentially representing present-day conditions, indicated by the 1975 to 2007 period. The latter period displays elevated low flows but reduced high and flood flows relative to the 1932-1968 flow conditions (Figure E14).

The patterns of sediment transport remain similar for the two periods, although the discharges representing the flow classes are lower. Relative to the assumed natural (1932-1968) flow patterns, in recent times (1975-2007) there has been an approximate 20% reduction in the potential to transport fines (silts and fine sand) and a 25% reduction in the potential to transport gravels and small cobbles.

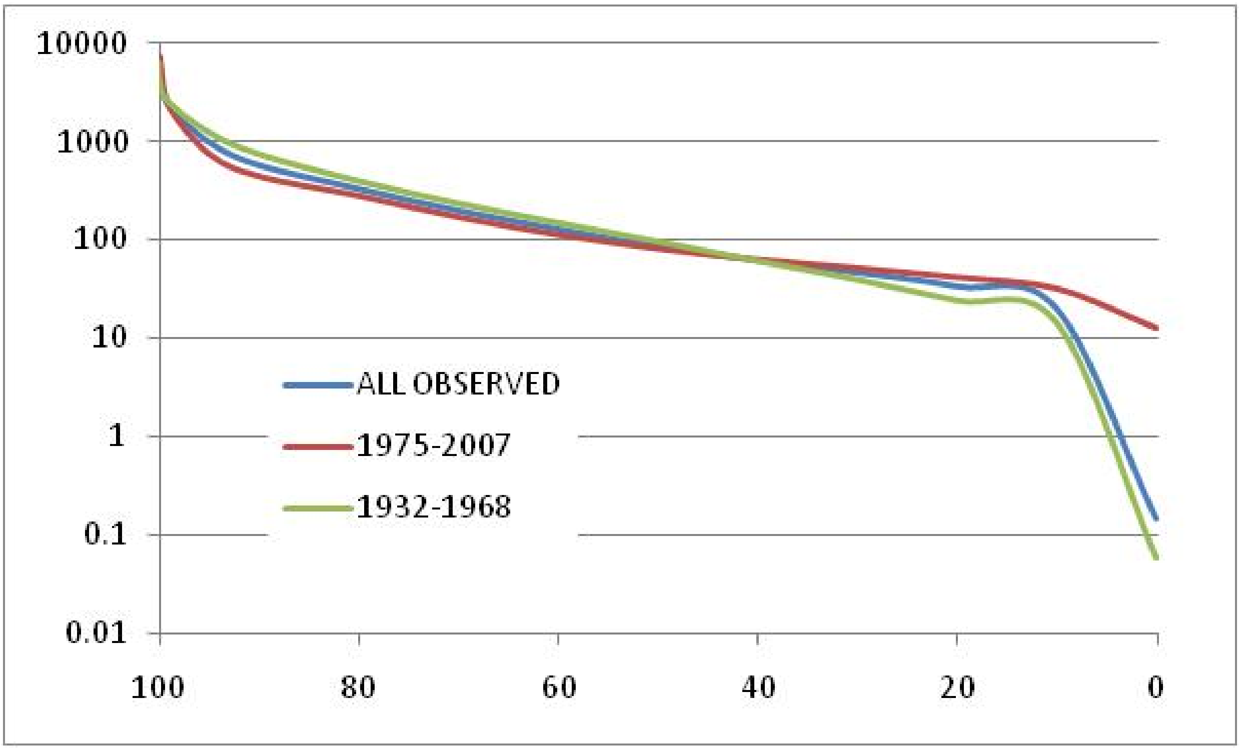


Figure E14 Flow duration curve (m^3/s on a log scale) of the daily observed data from 1932 to 2007

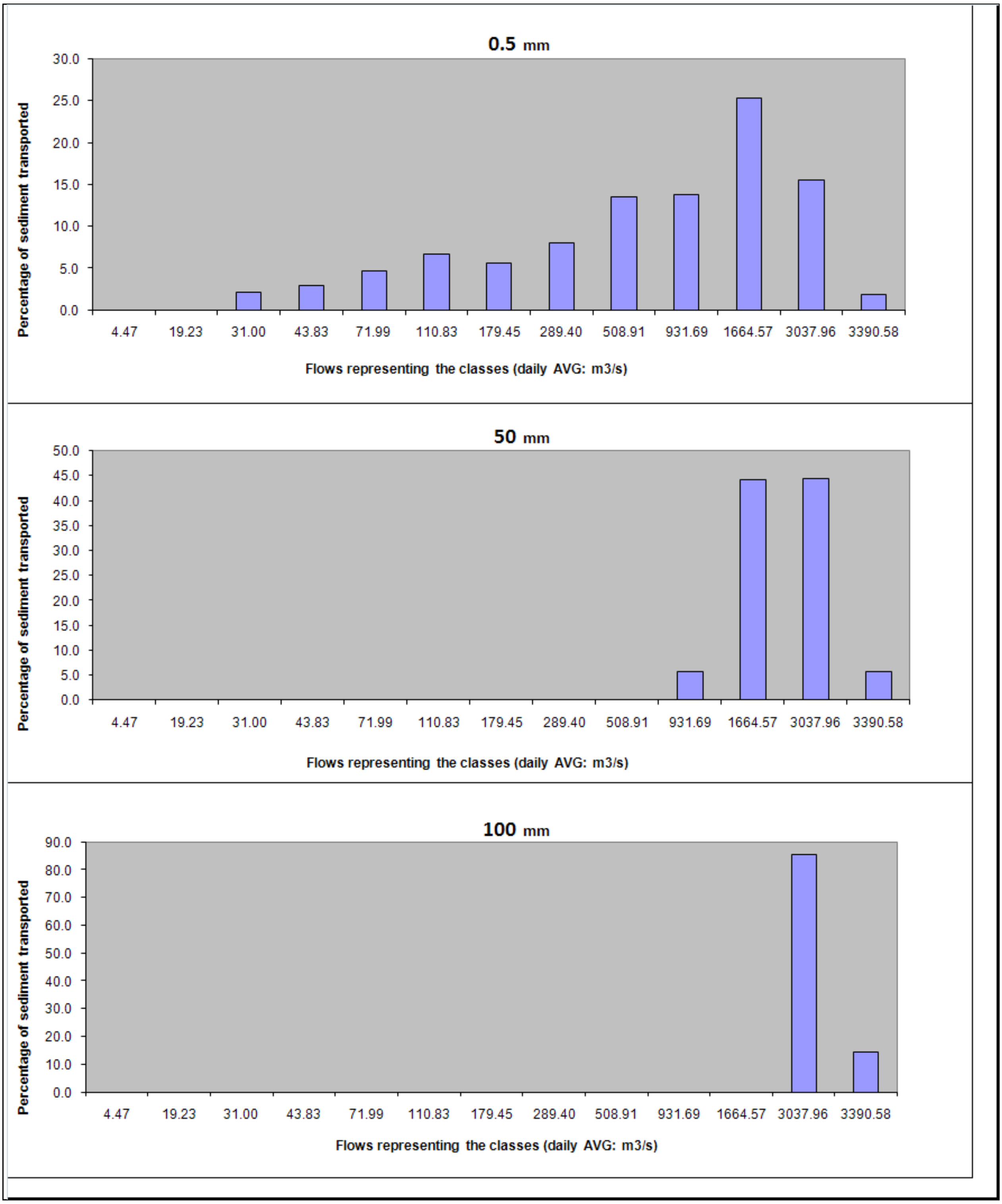


Figure E15 PBMT results for the 1932-1969 (pre-large dams) period

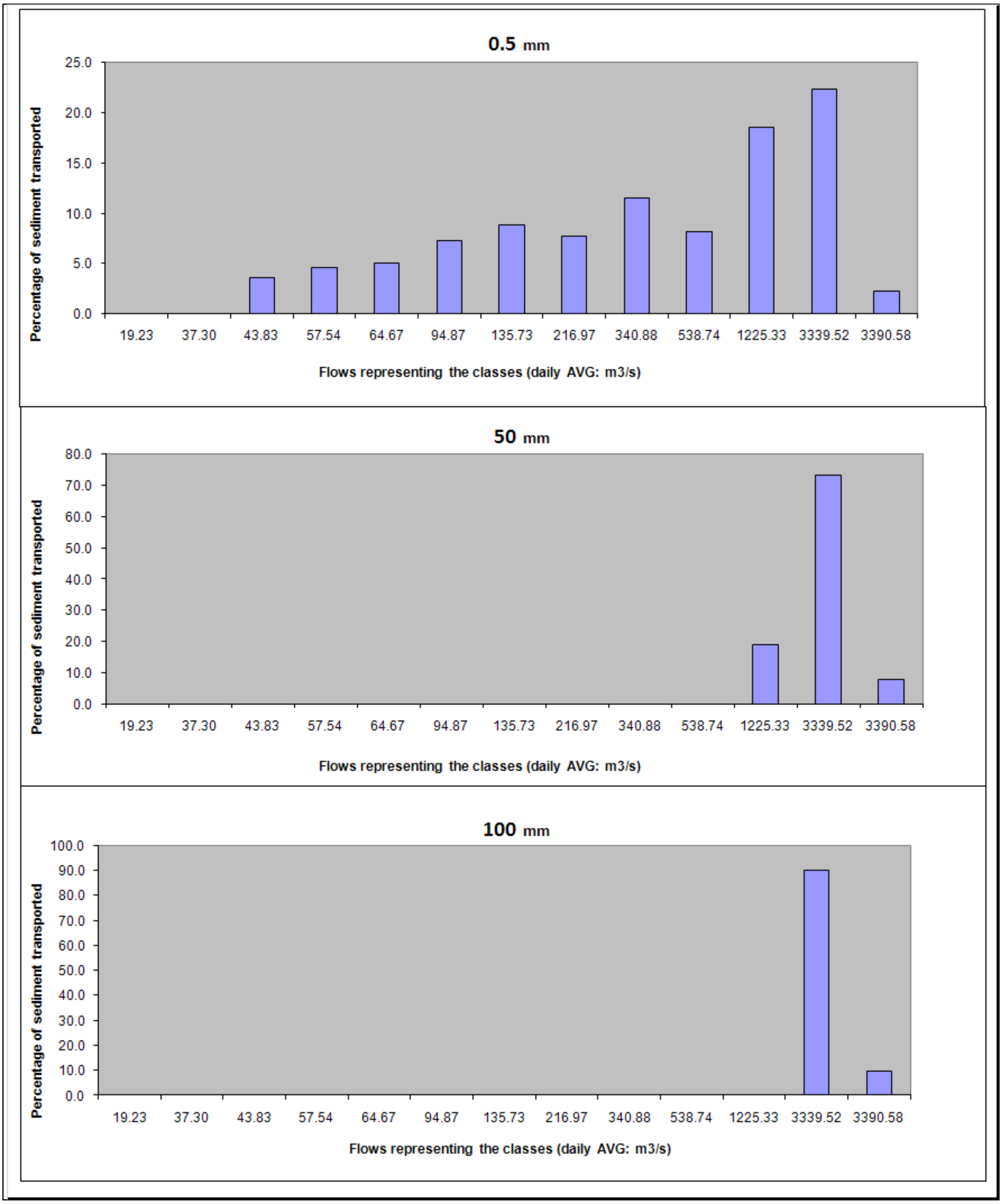


Figure E16 PBMT results for the 1975-2007 (post-large dams) period

E3.5.2 EFR O3

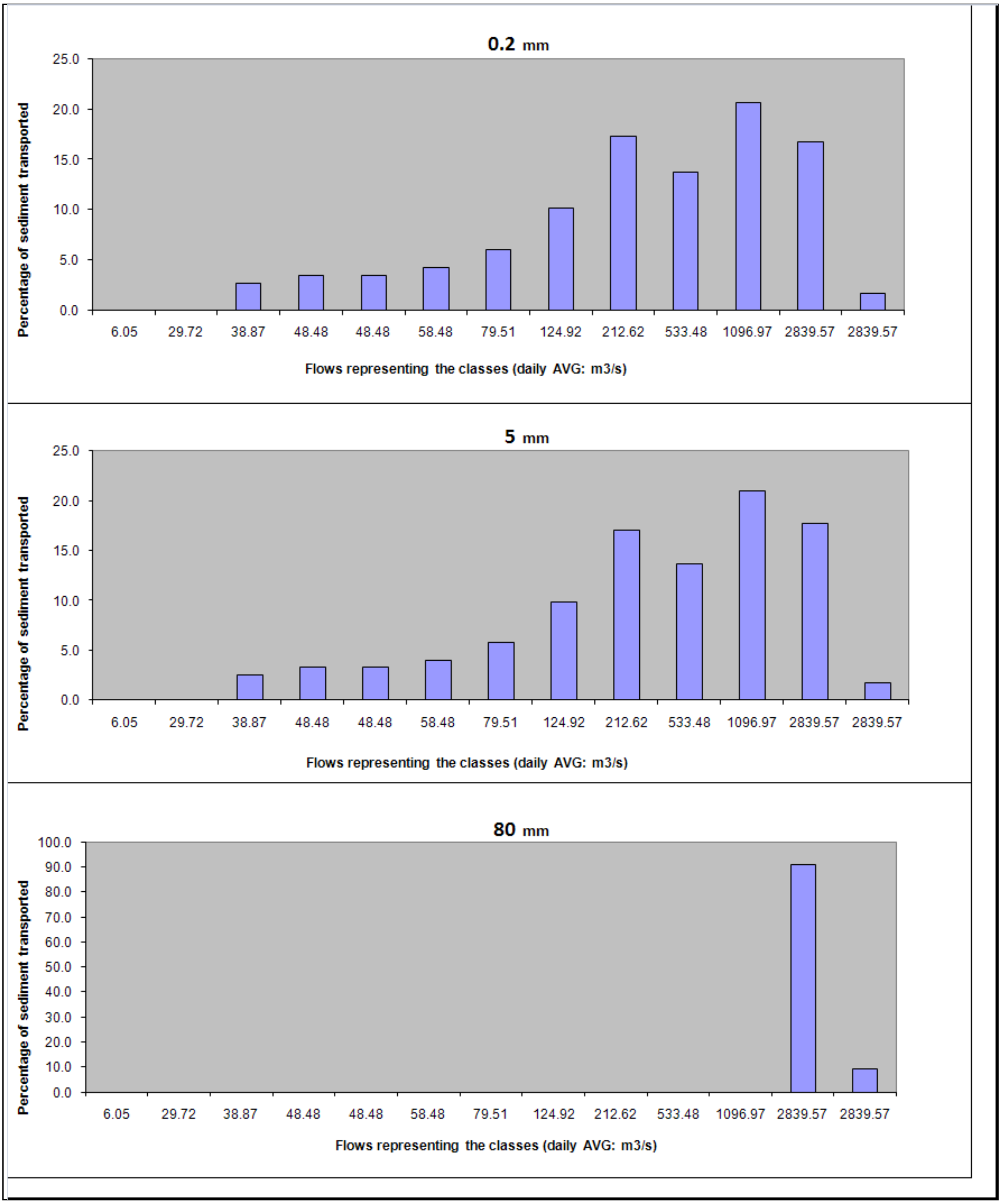


Figure E17 PBMT results for the 1935-1969 (pre-large dams) period

E3.5.3 EFR O4

At EFR 4, a very long flow record enabled us to separate out a “near natural” record (from 1935 to 1968 – prior to the operation of any large dams) and a flow record relative of more recent flow conditions (essentially representing present-day conditions, indicated by the 1975 to 2010 period. The latter period displays elevated low flows but reduced high and flood flows relative to the 1932-1968 flow conditions.

The patterns of sediment transport remain similar for the two periods, although the discharges representing the flow classes are lower. Relative to the assumed natural (1935-1968) flow patterns, in recent times (1975-2010) there has been an approximate 40 to 50% reduction in the potential to transport fines and sands and a 27% reduction in the potential to transport gravels.

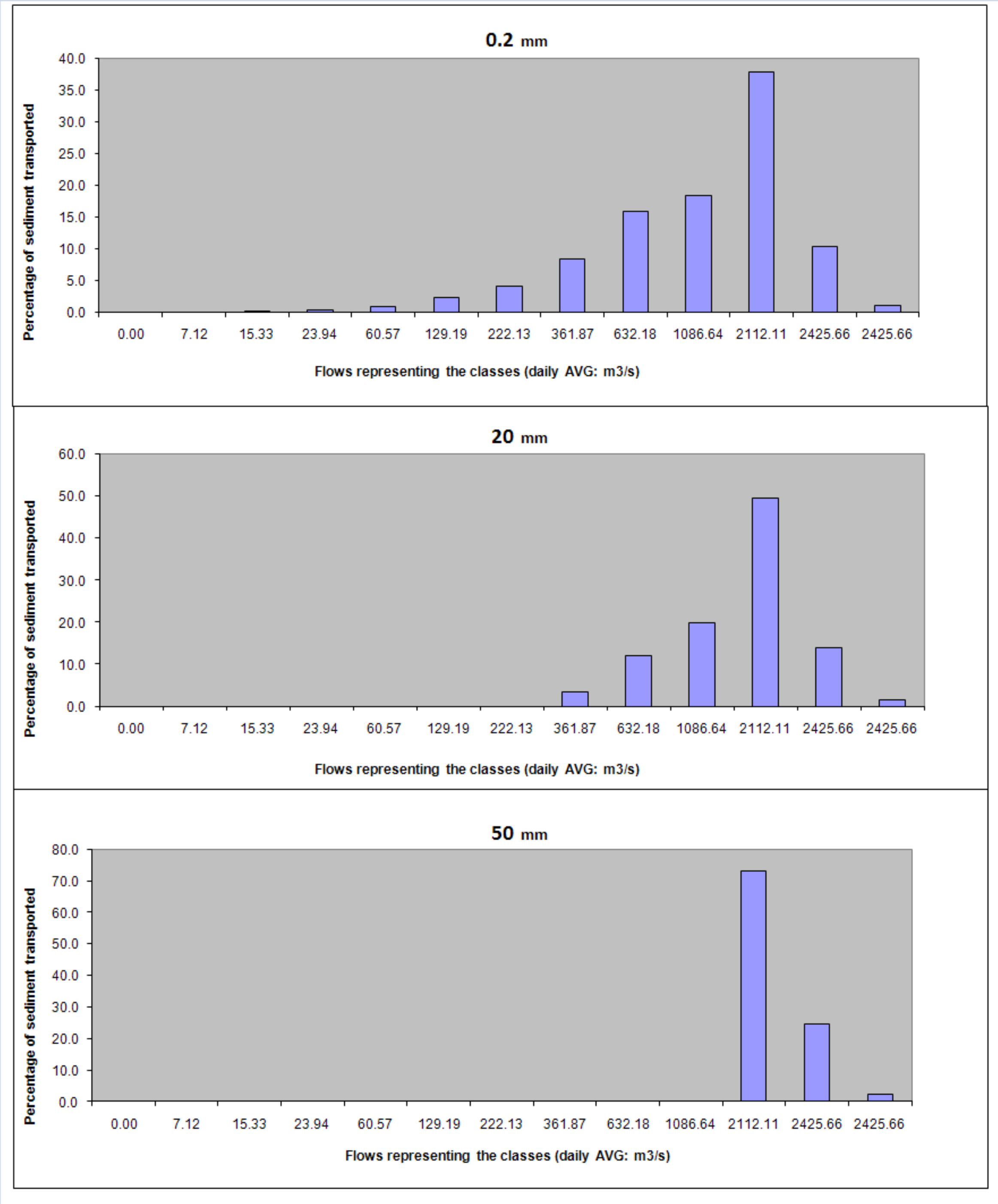


Figure E18 PBMT results for the 1935-1969 (pre-large dams) period

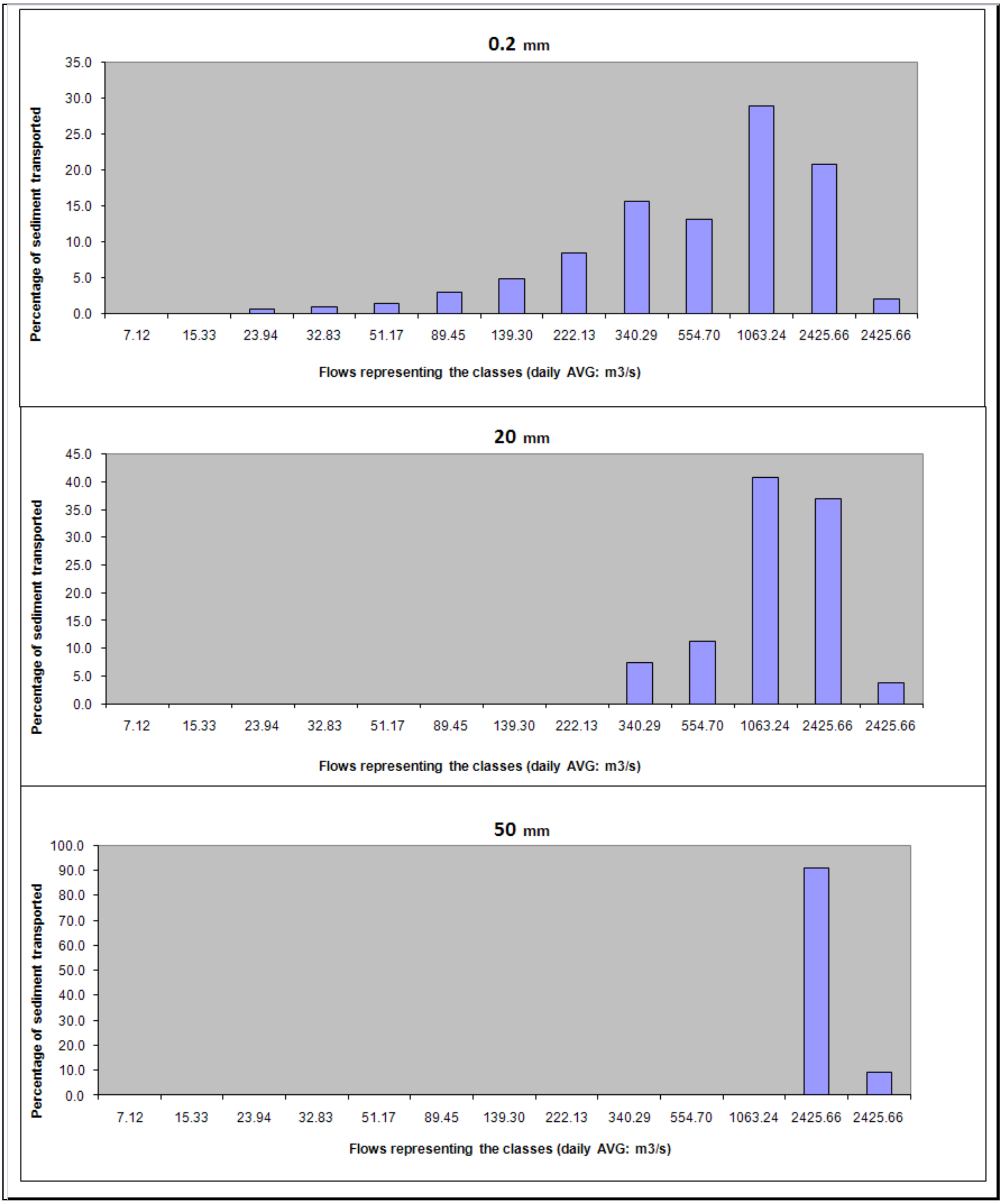
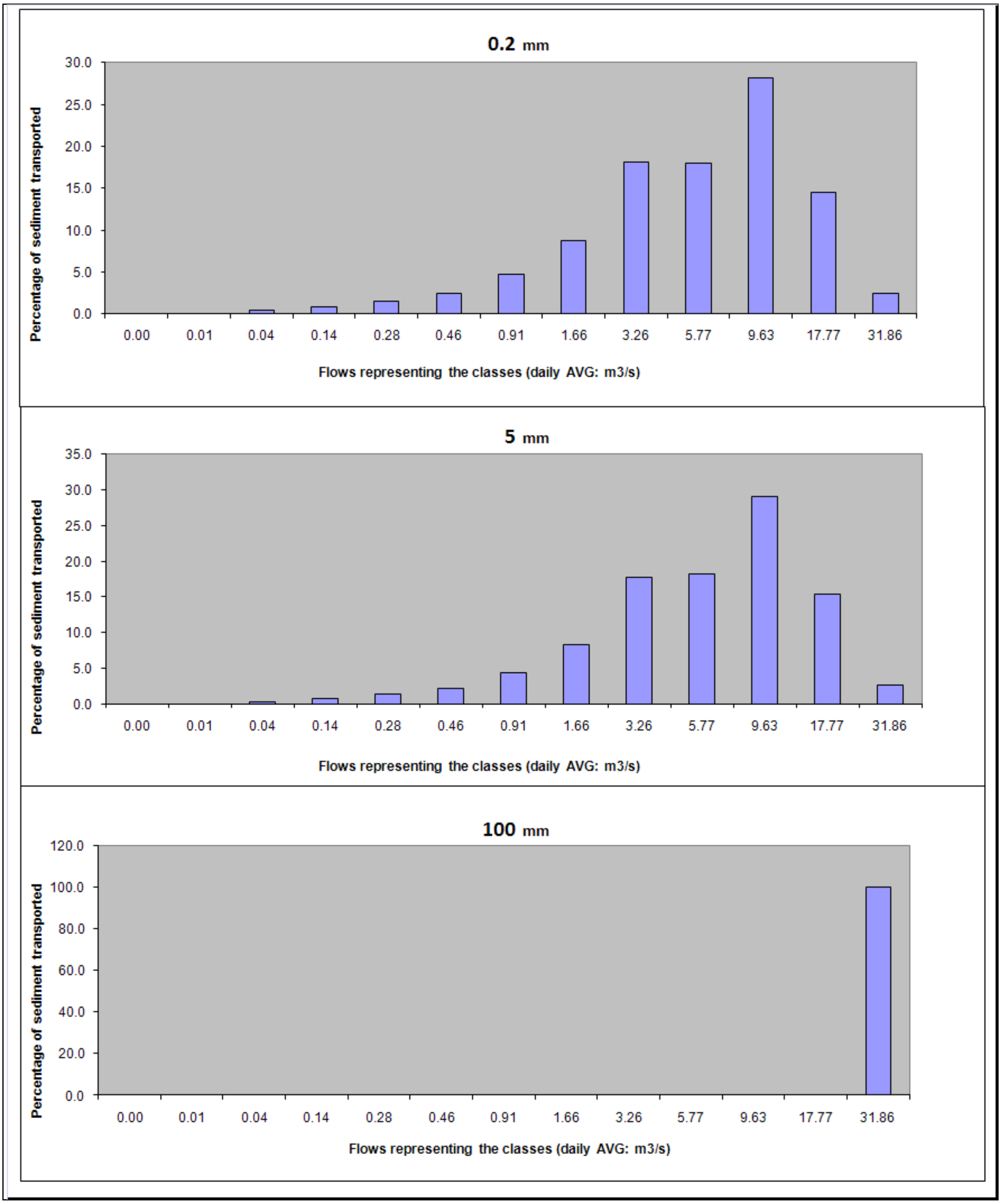
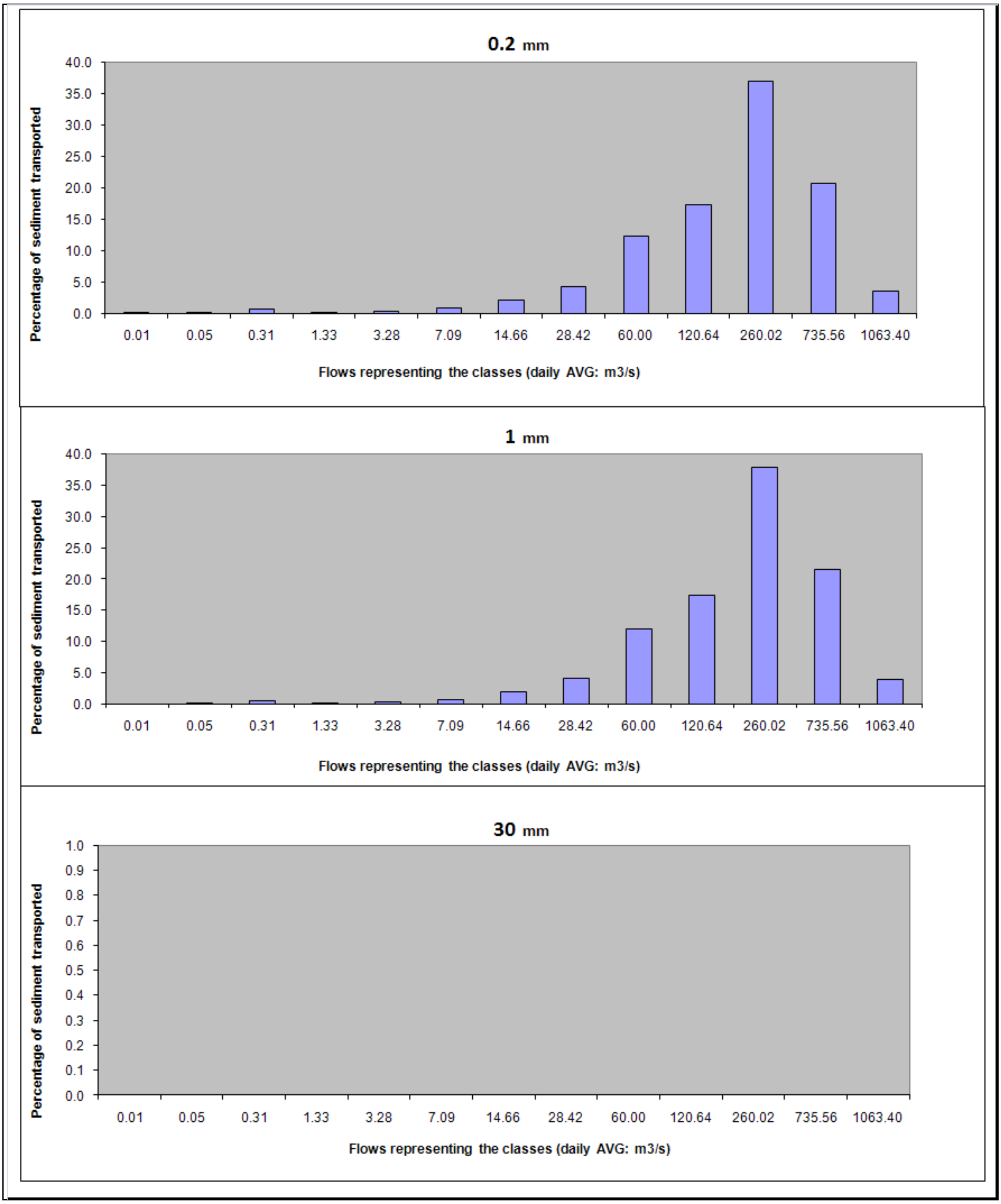


Figure E19 PBMT results for the 1975-2010 (post-large dams) period

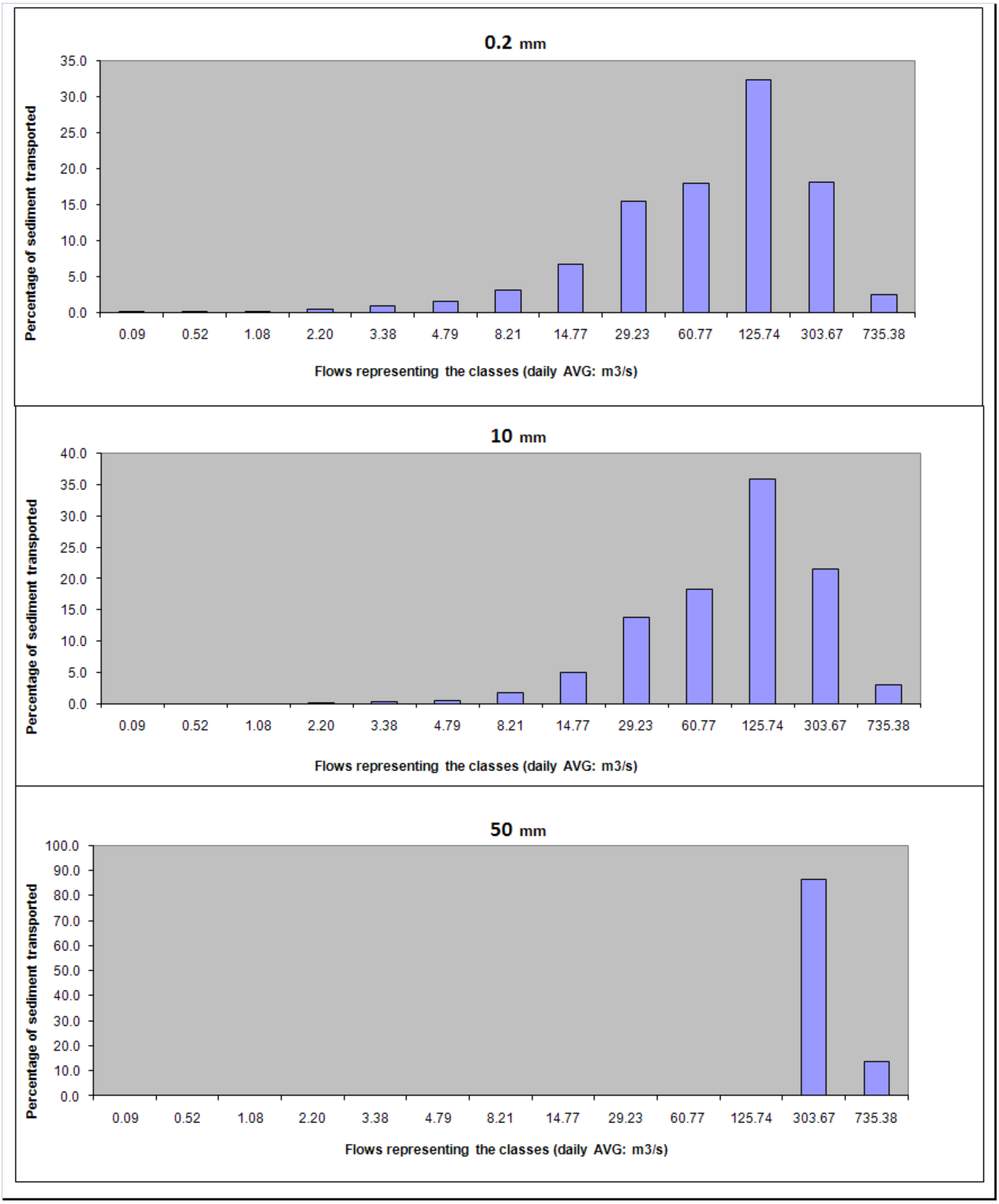
E3.5.4 EFR C5


0.2 mm
Percentage of sediment transported
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.00 0.01 0.04 0.14 0.28 0.46 0.91 1.66 3.26 5.77 9.63 17.77 31.86
Flows representing the classes (daily AVG: m3/s)
5 mm
Percentage of sediment transported
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.00 0.01 0.04 0.14 0.28 0.46 0.91 1.66 3.26 5.77 9.63 17.77 31.86
Flows representing the classes (daily AVG: m3/s)
100 mm
Percentage of sediment transported
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.00 0.01 0.04 0.14 0.28 0.46 0.91 1.66 3.26 5.77 9.63 17.77 31.86
Flows representing the classes (daily AVG: m3/s)

E3.5.5 EFR C6


0.2 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)
0.01
0.05
0.31
1.33
3.28
7.09
14.66
28.42
60.00
120.64
260.02
735.56
1063.40
1 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)
30 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)

E3.5.6 EFR K7


0.2 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)
10 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)
50 mm
Percentage of sediment transported
Flows representing the classes (daily AVG: m3/s)

E3.6 EFR M8: ESTIMATING ECOLOGICAL WATER REQUIREMENTS FOR WETLANDS AND EVALUATION OF SCENARIOS

No sediment transport modelling was conducted at EFR M8. This site is a wetland system and is not controlled or maintained by sediment transport, so the approach is not suitable for these types of water courses. Cues for identifying water requirements of the wetland rely heavily on vegetation and other biotic indicators.

Much of the original inflow to this site has been diverted by a weir, and a road crossing at the EFR site has created an artificial backup area that is creating unsuitable wetland habitat conditions for much of the endemic biota. The assessment at this site considered a range of possible scenarios whereby the impoundment level (and artificial backup zone) is reduced, and/or the inflows to the site are reduced.

Hydraulic modelling provided estimates of the area of backup that could be expected under the various lowering of the impoundment scenarios. Hydrological modelling of the impoundment site, calibrated to the measured in- and outflows at the time of the site visit, provided some coarse estimates of the range of increased or decreased flows that could be expected downstream of the impoundment under the various scenarios. These outflows (see Table below) are critical to maintain the once-extensive wetland areas between this site and Mafikeng.

Using the above data, estimates were made on the expected EC changes to the wetland at the site (EFR M8) and for the larger Management Resource Unit (MRU A). Scenarios 1 and 2 (lower impoundment level by 2 and 3 metres respectively) offer the best scenario for ecological improvement of the wetland, since the section currently impounded will improve, and more water will flow to the downstream wetland sections.

<table>
<tr><th colspan="2" rowspan="3">Scenario Description</th><th colspan="6">ECOLOGICAL CONSEQUENCES</th></tr>
<tr><th colspan="4">EFR Site 8
(small reach)</th><th colspan="2">MRU A
(larger upper wetland area)</th></tr>
<tr><th>INFLOW
(l/s)</th><th>Area of backup behind impound-ment
(ha)</th><th>OUTFLOW
(l/s)</th><th>Estimated wetland PES at EFR Site 8 (EC)</th><th>% change in outflow from impound-ment (change to INFLOW for down-stream wetland area)</th><th>Estimated wetland PES of WRU A (EC)</th></tr>
<tr><td colspan="8">PRESENT DAY (inflow of 150l/s)</td></tr>
<tr><td>site visit (PD)</td><td>Present Day conditions (at time of site visit)</td><td>150</td><td>24</td><td>80</td><td>D</td><td>0</td><td>C</td></tr>
<tr><td colspan="8">SCENARIOS TO REDUCESIZE OF IMPOUNDMENT (inflow remains at 150l/s)</td></tr>
<tr><td>Scenario 1</td><td>drop road crossing by 1.2m</td><td>150</td><td>12</td><td>108</td><td>C/D</td><td>+ 35</td><td>C</td></tr>
<tr><td>Scenario 2</td><td>drop road crossing by 2m</td><td>150</td><td>5</td><td>125</td><td>C</td><td>+ 56</td><td>B</td></tr>
<tr><td>Scenario 3</td><td>drop road crossing to bed level</td><td>150</td><td>3</td><td>130</td><td>C</td><td>+ 63</td><td>B</td></tr>
<tr><td colspan="8">SCENARIO TO REDUCE INFLOW (INCREASE ABSTRACTION)</td></tr>
<tr><td>Scenario 5</td><td>inflow reduced to 75 l/s</td><td>75</td><td>24</td><td>5</td><td>D</td><td>-94</td><td>D/E</td></tr>
<tr><td>Scenario 6</td><td>inflow reduced to 110 l/s</td><td>110</td><td>24</td><td>40</td><td>D</td><td>-50</td><td>D</td></tr>
</table>

E3.7 RESULTS: FLOOD REQUIREMENTS FOR GEOMORPHOLOGY

E3.7.1 EFR O2

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY		
Class	**Size**		**PES**	**REC**	**AEC down**
I	150-200	Regular wet season flushes to remove fines and activate gravels. These flows transport about 10% of the fines at the site and will activate the low seasonal channels.	2		1
II	300-400	Scouring flood to remove fines and activate gravels. This flow class transports more than 10% of the fines at the site. These flows will also activate many of the backwaters.	1:2		1:3
III	850-1000	This flow class transports more than 20% of the fines and is the effective discharge for the site. Gravels and some larger elements will be activated and thus inhibit embeddedness. These flows will scour large seasonal channels and associated backwater areas and remove some of the encroaching vegetation.	1:5		1:5
IV	2000+	This flow class is the effective discharge for gravels and cobbles, as well as being responsible for transporting about 20% of the fines. These large floods will scour the channels and reset the vegetation, especially that encroaching on and stabilising the bars.	1:10		1:10
Confidence:		**Comments**			
3.5		Confidence is relatively high since the planform behaviour in response to large floods is well-known for these bedrock anastomosing reaches. The hydrological record available for the site is extremely long – more than 70 years – with less than 0.5% of missing data from this record. This allowed for a higher confidence assessment of the site. The frequency of floods requested is low relative to natural conditions, but this is because sediment loads are lower (due to upstream trapping) and thus fewer floods are required to prevent excessive sedimentation.			

E3.7.2 EFR O3

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY	
Class	**Size**		**PES**	**AEC down**
I	120	Regular wet season flushes to remove fines and activate small gravel material. This flow class transport about 10% of the fines at the site and will thus scour accumulated fines from the bed. There should be some reworking of the active gravel bars during these floods.	3	2
II	210	Scouring flood to remove fines and activate gravels. This flow class transports more than 15% of the fines at the site and is an important flood for scouring and fines removal.	1	1
III	1000	This flow class transports more than 20% of the fines and is the effective discharge for fines at this site. Gravels and some larger elements will be mobilised and thus inhibit embeddedness.	1:5	1:5
IV	2500+	This flow class is the effective discharge for large gravels and cobbles - 80% of transport of these bed elements occurs in this flood class. There should be scouring and reworking of bed and bar deposits in this flood. This flood cannot be managed – it occurs during extremely high rainfall years - and was not included further in the study or flood motivations.	1:10	1:10
Confidence:		**Comments**		
4		Confidence is relatively high at the site since the flood requirements identified through sediment transport modelling matched the morphological indicators at the site and the cues identified by the vegetation specialist. The frequency of floods requested is low relative to natural conditions, but this is because sediment loads are lower (due to upstream trapping) and thus fewer floods are required to prevent excessive sedimentation.		

E3.7.3 EFR O4

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY	
Class	Size		PES	AEC down
I	170	Regular wet season flushes to remove fines and activate small gravel material. This flow class transport about 8% of the fines at the site and will thus scour accumulated fines from the active channel bed.	3	2
II	340	Scouring flood to remove fines and activate gravels. This flow class transports more than 15% of the fines at the site and is an important flood for scouring and fines removal. Some scour of low bars and the bed will occur with these flows.	1	1
III	550	This is an important small scour flow for gravels and fines. The flood class is responsible for more than 10% of the sand and small gravel transport, so this will scour the bed and low bars.	1:2	1:2
IV	1000	This flood class transports more than 30% of the fines and more than 40% of the small gravels, acting as the present day effective discharge for fines and small gravels. Gravels and some larger elements will be mobilised and thus inhibit embeddedness. This flood class occurred almost annually under natural conditions.	1:3	1:3
Confidence:		**Comments**		
2.5		Confidence is slightly lower at the site because the morphological cues are less-well defined, hence confirming the flood requirements identified through sediment transport modelling to the morphological indicators was not very clear, and similarly the vegetation specialist had slightly lower confidence at this site than the upstream EFR O2 and O3. The frequency of floods requested is low relative to natural conditions, but this is because sediment loads are lower (due to upstream trapping) and thus fewer floods are required to prevent excessive sedimentation.		

E3.8 EFR C5

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY	
Class	Size		PES	AEC down
		Regular wet season flushes to remove fines and activate gravels. These flows transport about 30% of the fines and gravels at the site.	4	3
		Scouring flood to remove fines and activate gravels. This flow class transports more than 25% of the fines and gravels at the site, and is the effective discharge for the site.	2	1
		Annual scouring event that flushes fines, scours the bed and scours gravels and cobbles.	1:1	1:1
Confidence:		**Comments**		
2		Confidence in EFR determination for geomorphology at this site is low because: ▪ There are no clear morphological cues; ▪ The channel is rapidly eroding, so any high banks and terraces are not related to the contemporary hydraulics of the site (channel is deepening and widening, so the flows that deposited terrace sediments no longer reach those stages as often); ▪ The available hydrology – vital for undertaking sediment transport potential to identify key flow categories for channel maintenance – is derived from a gauge far (60 km) downstream, and the gauge itself does not record accurate flows. However, using scaled hydrological data, the results from the sediment transport modelling due coincide moderately well with the other biotic cues at the site.		

E3.8.1 EFR C6

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY	
Class	**Size**		**PES**	**AEC up**
	50-70	Regular wet season flushes to remove fines and activate gravels. These flows transport about 15% of the fines at the site.	4	5
	100-130	Scouring flood to remove fines and activate gravels. This flow class transports more than 15% of the fines at the site.	2	3
	200-400	Scouring flood to remove fines and activate gravels. This flow class transports more than 35% of the fines and gravels at the site, and is the effective discharge for the site (the flow class responsible for most sediment movement).	2:3	1:1
Confidence:		**Comments**		
2		Confidence in EFR determination for geomorphology at this site is moderate to low because: ▪ There are few clear morphological cues; ▪ The channel is aggrading due to the assumed backup impacts of the dam, the very elevated sediment inputs from upstream, and occasional bottom release sediment from the upstream dam. This is smothering the morphology, and also means that very large floods have lost their ability to scour the bed. This reach is therefore storing increasing volumes of sediment, altering hydraulic profiles and reducing access of biota to the original coarse bed sediment habitats. Additionally, the available hydrology – vital for undertaking sediment transport potential to identify key flow categories for channel maintenance – is derived from a gauge far upstream of the EFR site.		

E3.8.2 EFR K7

FLOODS		GEOMORPHOLOGICAL MOTIVATIONS	FREQUENCY	
Class	**Size**		**PES**	**AEC down**
	14	Regular wet season flows to flush fines from the active channel bed, and to activate the low bars and side channels/backwaters.	4	2
	30 - 60	Scouring flood to remove fines, turn over gravels and inundate the lower terrace (active bars). This flow class is responsible for about 30% of the fines and gravels transported through the site annually.	3	2
	125	These large, infrequent scouring floods are required to mobilise the bed (gravels and cobbles) and keep sedimentation in check and prevent embeddedness. It is the effective discharge for the site, responsible for more than 35% of the fines and gravels transported through the site annually.	1:1	1:1
	300	This large scouring flood will remove fines and mobilise the gravel and cobbles. It is the effective discharge for the small cobbles at the site.	1:3	1:3
Confidence:		**Comments**		
4		Confidence in EFR determination for geomorphology at this site is high because: ▪ There are morphological cues; ▪ The available hydrology is derived from a long (40 year) record from a relatively reliable gauge immediately upstream of the site and the high flow hydrology is only moderately altered from Reference; ▪ There are no large dams, or extensive catchment-wide erosion, so the sediment load is relatively natural. This reach is therefore close to Reference condition, and the hydrological records and sediment data are representative of the original condition.		

E3.8.3 EFR M8

There are no explicit flow requirements for geomorphology at EFR M8. The site is a groundwater fed wetland and therefore not dependent on any flushing flows or channel maintenance flows as such; especially not in this uppermost reach at the EFR site. No floods are necessary for the system as it is baseflow dependent (dependent on flows from the dolomite aquifer). Various scenarios of changes to present day baseflows, and some scenarios of non-flow changes to the impoundments, were assessed to determine overall changes to the wetland that are likely to result under each of these scenarios. These provide a range of options to assess possible future changes and how these may impact upon the wetland at the EFR site.

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