LOWER ORANGE RIVER MANAGEMENT STUDY (LORMS)

TASK 5.1:

ECOLOGICAL ISSUES PERTAINING TO THE CONSTRUCTION OF LARGE DAMS IN THE LOWER ORANGE RIVER

DRAFT REPORT

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EXECUTIVE SUMMARY

Background

The Lower Orange River Management Study (LORMS) has identified three possible sites for a large dam on the lower Orange River. These are dam sites located at:

- Boegoeberg
- Komsberg; and
- Boegoeberg.

Various options with respect to dam wall height and inundation levels are being considered for dams at each of the above-mentioned locations, viz:

Vioolsdrif: Dam wall heights of 25 m; 44 m and 55 m;
Komsberg: Dam wall height of 23 m;
Boegeberg: Dam wall height of 42 m.

Study area

The LORMS focussed on the lower Orange River from the confluence of the Vaal to the mouth of the Orange River. However, the riverine ecological work undertaken as part of LORMS has focussed on the river reach between Augrabies and Onseepkans, with some limited consideration of the upstream sections of the study area, in particular the reach near Boegoeberg.

Potential impacts of a dam on the lower Orange River

The potential barrier and inundation effects (excl. hydrology – see Task 8.3) impacts of a dam on the lower Orange River on the riverine ecosystem include:

- entrapment of sediment;
- altered sediment composition in the downstream river;
- thermal stratification and its effects on the downstream aquatic biota;
- eutrophication and algal blooms;
- elevated salinities;
- threat of bilharzia, and other parasites;
- loss of and changes to riparian vegetation;
- provision of habitat for invasive aquatic vegetation;
- entrapment of woody debris;
- entrapment of disseminules;
- spread of pest species invertebrates;
- creation of a barrier to migration;
- fragmentation of habitat with associated fitness and genetic implications;
- inundation of fish and invertebrate habitat;
- provision of a haven for alien fish species;
- elevated parasitic infections in fish;
- construction related impacts, such as:
    - increased turbidity
    - chemical pollution.

The assessment presented here suggests that:

- all of the proposed options will have a detrimental impact on the riverine ecosystem.
- a dam at Boegoeberg would have the least impact relative to the other options;
- a dam at Vioolsdrif would have the most impact relative to the other options, particularly the options with the dam walls of 44 and 55 m.
- dams with lower dam walls have relatively less impact than those with higher dam walls.

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1 INTRODUCTION

The Lower Orange River Management Study (LORMS) has identified three possible sites for a large dam on the lower Orange River. These are dam sites located at:

- Vioolsdrif;
- Komsberg; and
- Boegoeberg.

Various options with respect to dam wall height and inundation levels are being considered for dams at each of the above-mentioned locations. Southern Waters was requested to provide a coarse-level assessment, based on readily available information, of the potential ecological implications on the lower Orange River of a dam situated at any one of these three locations.

3.1 ACTIVITIES

The following activities were undertaken:

- site visits to the proposed Vioolsdrif Drift and Boegeberg dam sites;
- a helicopter/ fixed wing aeroplane aerial reconnaissance of the lower Orange River;
- a literature survey of ecological issues related to large dams on rivers;
- a specialist session at the Task 8.3 workshop, where the ecological issues specific to the lower Orange River where discussed and highlighted;
- individual discussions with key biophysical and engineering specialists;
- write-up of this report.

3.2 LIMITATIONS OF THE STUDY

The study was limited to six days, inclusive of a 3.5-day site visit. The study was based on existing information and no new data were collected on the Orange River. Furthermore, this report is limited to the barrier and inundation effects of a dam on the riverine ecosystem.

<u>Effects on the flow regime in the downstream river and estuary were excluded from this study as they are dealt with separately under Task 8.3.</u>

3.3 STUDY AREA

The LORMS focussed on the lower Orange River from the confluence of the Vaal to the mouth of the Orange River. However, the riverine ecological work undertaken as part of LORMS has focussed on the river reach between Augrabies and Onseepkans, with some limited consideration of the upstream sections of the study area, in particular the reach near Boegoeberg.

A detailed description of the Orange River within the study area is provided in the report for Task 8.3.

3.4 OPTIONS FOR DAM SIZES AT EACH SITE

The dam size options under consideration for the three potential sites are:

Vioolsdrif: Dam wall heights of 25 m; 44 m and 55 m;

Komsberg: Dam wall height of 23 m;

Boegoeberg: Dam wall height of 42 m.

The assessments may result in the selection of a preferred option, out of the possible five options listed above, for further investigations.

2 ECOLOGICAL ISSUES PERTAINING TO THE CONSTRUCTION OF LARGE DAMS IN THE LOWER ORANGE RIVER

3.1 INTRODUCTION

The effects of large dams (defined as having either a wall height of greater or equal to 15 m (McCully 1996) or a reservoir capacity of greater than 3 x 10^6 m^3 (Baur & Rudolph 2000)) on aquatic ecosystems have been reviewed extensively (e.g. Ward & Stanford 1979; de Moor 1986; McCully 1996; Beilfuss ***et al.*** 2002). Large dam(s) may cause one or more of the following: inundation of key river habitat; loss of rare riverine features through inundation; a decline in water quality (e.g. Kafue River, Zambia); the erosion and collapse of river banks, deltas and coastlines (e.g. Nile River, Egypt) (McNeill 2000; McManus 2002); loss of agricultural land (e.g. Senegal River, Senegal) (Adams 2000); collapse of a river fishery (e.g. lower Zambezi River, Mozambique) (Beilfuss ***et al.*** 2002); decline of an important estuarine wetland (e.g. Berg River, South Africa), or the decline of a marine fishery dependent on that estuary as a nursery area for juvenile fish (e.g. Senegal River) (Kloff & Pieterse 2002). Most of these environmental impacts had direct or indirect socio-economic costs.

3.2 IMPACTS OF DAMS ON RIVERS

A series of complex physical, chemical and biological processes occur in flowing rivers that link the watershed ecosystem from its headwaters to the sea. Longitudinal changes occur in the characteristics of river channel shape and slope, substrate and water chemistry, thereby creating physical gradients along the river course, to which the animal and plant life inhabiting the river have adapted to over thousands of years. Manufactured barriers on river systems interrupt the natural processes associated with these physical gradients, creating significant long-term effects on a river's biological integrity. Thus it follows that the impacts of large dams on aquatic ecosystems are not limited to the inundated upstream reaches and those immediately downstream of the dam wall. Regulation of flows and sediments in one part of a river can affect parts of the river tens or even hundreds of kilometres downstream. Furthermore, many of these impacts evolve slowly over years or even decades, and so may be difficult to link directly to a specific water-resource development.

The effects of dams on river ecosystems can be summarised into four categories:

1. **Physical Effects**, e.g.:
    a. Alteration of channel form, where the existing form is modified into a still water lake environment.
    b. Inhibition of sediment transport. Boulders, cobble, sand, gravel and finer materials are trapped in the dam, diminishing sediment in downstream reaches. This can result in streambed or bank erosion, and associated changes in channel form downstream of the dam wall. Associated with this is a build up of sediment in the impoundment, reducing storage capacity and yield, and in the worse case resulting in dams becoming wetlands over decades.
    c. Interruption of the river continuum: Vertical drops in elevation effectively curtail the natural physical gradients of the river;

   d. Reduction in downstream habitat diversity: Barriers block the downstream movement of woody debris, which provides valuable habitat in lower rivers;
   e. Decreased light penetration to the riverbed in the impounded section, promoting anoxic conditions.
2. **Hydrological effects**, e.g. (see Task 8.3 for more detail):
   a. Reduction in low flow: Lowflows define the basic seasonality of the river: its dry and wet seasons, and degree of perenniality. The different magnitudes of low-flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.
   b. Reduction in flow variability: Fluctuating discharges create mosaics of areas inundated and exposed for different lengths of time. The resulting physical heterogeneity determines the local distribution of species: higher physical diversity enhances biodiversity.
   c. Reduction in flood peaks: Large floods provide scouring flows that influence the form of the channel. They mobilise coarse sediments, and deposit silt, nutrients, eggs and seeds on floodplains. They inundate backwaters and secondary channels, and trigger bursts of growth in many species. They re-charge soil moisture levels in the banks, inundate floodplains, and scour estuaries thereby maintaining links with the sea.
   d. Elimination of small floods: Small floods are of great ecological importance in semi-arid areas in the dry season. They stimulate spawning in fish, flush out poor-quality water, mobilise smaller sediments and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migrations of fish and germination of riparian seedlings.
3. **Water quality effects**, e.g.:
   a. Alterations to downstream temperature regimes: Stratification of temperature through the water column can result in surface waters being warmer and deep water very cold. This can lead to ‘thermal shocks’ to the downstream river as a result of the release of water that is aseasonally too warm or too cold.
   b. Entrapment of pollution: As pollutants move downstream, they are trapped with the fine sediment in impoundments.
   c. Entrapment of nutrients: As nutrients move downstream, they are trapped in impoundments, inducing over-enrichment, and subsequent algal blooms.
   d. Supersaturation of nitrogen gas: As water spills over the dam wall, supersaturation of nitrogen gas can occur with potential impacts on fish.
4. **Biodiversity effects**, e.g.:
   a. Isolation of populations: Fragmentation of habitats as a result of an artificial barrier can lead to isolation of biotic populations, and subsequent genetic diversion.
   b. Reduction in fitness of populations: Fragmentation of habitats inhibits gene flow between individuals of a particular species and can reduce the biological fitness of aquatic populations (in-breeding);

c. Death of fish and other organisms: Fish and other organisms are killed in turbines, pumps and spillways.
d. Reduced aquatic productivity, largely as a result of habitat fragmentation.
e. Impairment of migration. Barriers impair ***upstream and downstream*** migration of a host of aquatic animals, including fish, crabs, frogs, eels and otters.
f. Impairment of insect populations. The abundance and diversity of insect populations is reduced through, inter alia: inundation of river habitat; reduction/change in food supply downstream; changes in water quality and habitat impacts downstream; upstream siltation; altered (and usually less variable) flow regimes;
g. Encouragement of pest species. The impacts mentioned in f above, often provide the template for a single species, which is best suited to the changed conditions (e.g., to elevated water temperatures, increased levels of suspended material, and constant flow) and outcomplete other species and increase to pest proportions.

5. Social effects, e.g.:

a. Loss of fishing catches/revenue: The impacts on fish reproduction in the river and estuary can reduce catches, particularly in near-shore fisheries.
b. Impaired water quality. Factors such as algal blooms in an impoundment can have serious health implications for people (due to cyanobacteria and diatoms) dependent on the downstream river for water supply, as well as physical (blockage) problems in irrigation systems.

3.3 COMMENTS SPECIFIC TO THE LOWER ORANGE RIVER

The following issues, specific to the Orange River were highlighted at the Task 8.3 workshop (see summary in Appendix A). These have been divided up into the disciplines represented at the workshop, ***viz***.: geomorphology, water chemistry, botany, ichthyology and invertebrate ecology. Hydrology is not addressed here as it formed the focus of the Task 8.3 work.

Geomorphology

A dam in any of the proposed locations could impact on the channel structure through the following mechanisms:

Entrapment of sediment: The natural processes of scouring and deposition will be altered through the entrapment of sediments and changes in the hydrological regime. For instance, the supply of gravel to the downstream river will be reduced, thereby reducing the formation of bars and islands.

Altered sediment composition: The sediments in the reaches distal to the dams are likely to have a larger proportion of fine material than at present. This is because: 1) the dam will trap the larger sediments, while fine grains stay in suspension, 2) the catchments feeding into the lower reaches of the Orange River are prone to deliver clay, and 3) the dam will reduce the flow of water and thus competence of the river to transport sediment. The nett result will be a smothering of habitat used by aquatic organisms. In contract, the reaches proximal to the dams are likely to be prone to armouring as a result of the release of 'sediment-hungry' water from the impoundments.

Water chemistry

With the exception of the nutrient loading from the Upington Waste Water Treatment Plant, an impact which disappears by the time Onseepkans is reached, the water quality in the study reach is dictated by return flows and events upstream of it, and ostensibly with major variations being generated in spills from the Vaal system. The algal problem is for the moment being generated in the SpitskopDam and passed into the reach via the Harts River.

Dams in southern Africa are not natural lakes and do not function as such. The water levels in undergo large fluctuations, and these artificial lakes do not have the requisite ecosystem structure (i.e., no structural habitat or established food webs) to enable them to assimilate the various inputs. Hence, artificial lakes are effectively sterile and with respect to water quality, provide little or no buffering against poor water quality generated in their upstream catchments.

A dam in any of the proposed locations will result in the importation of the upstream water quality problems into the lower Orange River. The issues of most concern include:
- Thermal stratification and its effects on the downstream aquatic biota (Benade, undated). Thermal stratification occurs at van der Kloof Dam at present, with detrimental downstream effects. Water temperature triggers a wide range of responses in aquatic plants and animals, and changes in temperature regimes downstream of a dam can retard or halt, ***inter alia***:
    - fish spawning and growth;
    - flowering times, growth rates and size at maturity or riparian vegetation.
- Eutrophication and algal blooms. There is an excellent chance that a dam in the lower Orange River will develop algal problems, particularly given the inputs from upstream. All of the major impoundments (Gariep, Cook's Lake, Disaneng, Lotlamoreng and Modimola) in the upstream reaches have Trophic Status classifications of eutrophic to hypertrophic (DWAF 2002), and act as growth nurseries for algal development, chiefly cyanobacterial (blue-green algae). It will be important to assess the nutrient state of the geology in the three proposed locations in order to assess the relative potential for eutrophication and algal blooms in each of the proposed dams.
- Pollution sinks: Large floods will flush pollution from existing and proposed operations, including mining operations, into the dams, particularly Vioolsdrif dam.
- Elevated salinities: Dam construction and river regulation usually lead to increases in riparian agricultural activities, especially irrigation (catchment utilisation) and thus an increase in irrigation return flows. This, in turn, will inevitably lead to agricultural pollution resulting in changes to the river oxygen content, pH, turbidity and conductivity.
- Bilharzia: The potential for increased temperatures, and slower flowing waters in the lower Orange River will increase the suitability of the lower river as habitat for bilharzia snails.

Botany

The Orange River represents a very important strip oasis in an otherwise inhospitable landscape. Apart from the effects of reduced flow in the downstream reaches (Task 8.3), other issues pertaining to the potential impacts of dams on the vegetation of the lower Orange River include:

- Loss of riparian vegetation: Dams usually do not have the substrate for rooted water plants as inundation levels often extend away from the natural riparian/floodplain areas into areas with very shallow and/or very poor soils, which makes it difficult for plants to establish themselves. Thus inundated riparian vegetation, which is dependent on the deeper soils and flowing waters alongside the channel usually do not re-establish on the dam margins. In the Boegoeberg area, the riparian vegetation is already impacted by agricultural and other activities, although areas of the rare Orange River Broken Veld may be affected. The proposed site for the Komsberg Dam is in a natural gorge, where the riparian vegetation is sparse, however sections of the river appear near Vioolsdrif are relatively natural, and would need to be surveyed before a full assessment of the impacts of inundation could be determined. It is worth noting that the threat to islands in the lower Orange River (see geomorphology) represents a major threat to the remaining riparian vegetation as much of the good-quality riparian vegetation in these reaches is to be found on these islands, as such the islands themselves represent valuable sources of seeds and vegetative material.
- Provision of habitat for invasive aquatic vegetation: Artificial lakes provide an ideal habitat for water hyacinth or other floating macrophytes to flourish.
- Changes in riparian vegetation: The sorts of effects described in geomorphology will provide habitat suitable for the encroachment and colonisation of plant species such as the American floating water fern (***Azolla filiculoides***), water weeds (***Potamogeton schweinfurthii***, ***P. pectinatus***, ***P. crispus,*** and ***Ludwigia stolonifera***) and the river reed (***Phragmites australis***). This, in turn, will promote the habitat possibilities and further artificial distribution of certain economically important invertebrate pest species, as well as Red Billed Quelea (***Quelea quelea***) of which individuals had already been observed as far downstream as the Orange River Mouth (Benade, undated).
- Entrapment of woody debris: Constructing a dam on the river would stop wood being washed down to the estuary. Information from other lower rivers (such as those in Australia) indicates that wood provides valuable snag habitat, and the implications of a reduction in supply to the estuary and lower river would need to be investigated.
- Entrapment of disseminules (seeds and parts of plants): Seeds of riparian plants are also trapped in dam basins, detrimentally affecting recruitment of these species in the river reaches downstream of the dam.

Invertebrate ecology

The invertebrate fauna of the middle and lower Orange River under natural conditions is likely to have been characterised by a low diversity of species capable of tolerating periodic cessation of flow, and extreme floods that carried high levels of suspended material. Such variation promotes the coexistence of a number of species, without one species dominating for extended periods. The extant and proposed dams on the Orange River promote more stable conditions, eliminating 'no flow' conditions and dampening flood events. Additional dams, such as those proposed for here are likely to have the following effects on the invertebrate communities of the lower Orange River:

- Spread of pest species: There is likely to be a spread of pest species, such as the introduced snail, ***Physa acuta***, the aquatic weed, ***Myriophylum*** spp., the blackfly, ***S. damnosum*** s.l., and ***Hydra***. The spread of ***Phragmites*** spp. Reeds is likely to increase habitat availability for some aquatic invertebrates, particularly blackflies.
- Entrapment of invertebrates: A dam would trap invertebrates presently carried down the Orange River, hereby reducing both the resistance and the resilience of the system.

Ichthology

The lower Orange River contains the most diverse fish assemblage in whole Orange River system, with the diversity increasing downstream of Augrabies. A dam in this reach could have the following impacts on the fish communities inhabiting the lower Orange River (excluding hydrological impacts – Task 8.3):

- Creation of a barrier to migration: The proposed dam walls would preclude the passage of fish. Thus the migrations up and down the Orange River would be halted. This would reduce access to spawning and/or feeding sites. In this regard, the Komsberg site, just downstream of the Augrabies Falls, would have the least impact, as small fish species cannot more past Augrabies Falls in any case. The height of the proposed dam walls may preclude the effective use of fish ladders, but the possibilities for these should be investigated in detail, and should be budgeted for adequately in the estimates of construction and on-going management costs. Animals other than fish, such as crabs, also migrate up- and downstream between river reaches. The proposed dam wall and reservoir would either hinder or completely halt such movements.
- Fragmentation of habitat: The proposed dam at Vioolsdrif would split the range of ***Barbus hospus***. Similarly, the other dams would result in the fragmentation of fish populations in the lower Orange River, resulting in genetic compartmentalisation and inbreeding of aquatic populations. This enhances the manifestation of poor genetic characteristics, weakening populations and may in some instances lead to extinctions (Benade, undated).
- Inundation of spawning and other habitat: The inundation of large sections of river channel would significantly reduce the available spawning habitat, thereby threatening the reproduction viability of fishes in isolated reaches. It is worth noting that 12 out of the 15 indigenous Orange River system freshwater fish species, including one unique Red Data listed endemic (***Barbus hospes***), one unique indigenous (***Mesobola brevianalis***), two endemic Red Data listed (***B. kimberleyensis*** and ***Austroglanis sclateri***) and two vulnerable indigenous (***B trimaculatus*** and ***B. paludinosus***) fish species occur in the river stretch between Augrabies Falls and the Orange River Mouth. Thus loss of habitat in this reach represents a major impact on the fish assemblage of the Orange River as a whole.
- Provision of a haven for alien fish species: Alien species, such as carp and ***Tilapia mosambicensis,*** tend to be more sensitive to high flow conditions than the indigenous species. These fish are, however, well suited to lentic conditions, are able to breed there, and are widespread in standing water bodies throughout South Africa. It is

therefore expected that population sizes of invasive species will increase significantly in the lower Orange River should the river be impounded. An impoundment would be a supply source for alien species from whence colonisation of the upstream and downstream reaches of the Orange River could take place, which would increase predation pressure on the indigenous species in non-impounded sections of river.

- Elevated parasitic infections in fish: A dam in the lower reaches is likely to exacerbate the trend of increased parasite loads in the freshwater fish.

3.4 RELATIVE IMPACTS ASSOCIATED WITH THE PROPOSED DAM OPTIONS

The location of the proposed dam on the lower Orange River will make a difference to the severity of some of the impacts highlighted above. At the workshop held for Task 8.3, a session was added during which the specialists were asked to comment on the relative impacts and opportunities associated with the various proposed dam options. Their comments are provided in Appendix 1, and summarised below.

In order to summarise the information in Section 3.3 and Appendix 1, a simple four-point rating scale (0-4) was used to assign relative severity of a series of potentrial impacts for each of the five proposed dam options, where:

0 = negligible;

1 = minor;

2 = moderate;

3 = severe.

The 'scores' were then summed to give an indication of the relative severity of the impacts associated with each option (Table 3.1).

Table 3.1 A preliminary rating of the relative severity of the impacts associated with each of the proposed dam options, based on the information in Section 3.2 and Appendix 1.

Location	**Vioolsdrif**	**Vioolsdrif**	**Vioolsdrif**	**Komsberg**	**Boegoeberg**
Wall height	25 m	44 m	55 m	23 m	42 m
Impact					
Impact of access road on tributaries	3	3	3	2	1
Altered sediment composition d/s	2	2	2	3	2
Thermal stratification[1]	2	3	3	2	3
Eutrophication and algal blooms	3	3	3	3	3
Inundation of riparian vegetation	2	2	3	2	1
Elevated salinities in d/s river	3	3	3	3	3

[1] Stratification will need to be checked.

Location	**Vioolsdrif**	**Vioolsdrif**	**Vioolsdrif**	**Komsberg**	**Boegoeberg**
Wall height	25 m	44 m	55 m	23 m	42 m
Threat of bilharzia, and other parasites	2	2	2	2	2
Provision of habitat for invasive aquatic vegetation	2	2	2	2	2
Inundation of fish and invertebrate habitat	2	2	3	3	1
Spread of pest species invertebrates	3	3	3	3	2
Creation of a barrier to u/s migration	3	3	3	1	3
Creation of a barrier to d/s migration[2]	3	3	3	3	2
Provision of a haven for alien fish species	3	3	3	3	2
Preliminary rating:	33	34	36	32	27

Based on the rating above, the following can be concluded:

- all of the proposed options will have a detrimental impact on the riverine ecosystem. In the simple system used above the maximum score would be 39 and a minimum score 0. Thus all the options were assigned scores that resulted in overall scores > 69% of the mximum possible score.
- a dam at Boegoeberg would have the least impact relative to the other options;
- a dam at Vioolsdrif would have the most impact relative to the other options, particularly the options with the dam walls of 44 and 55 m.
- dams with lower dam walls have relatively less impact than those with higher dam walls;
- at least the proposed 55 m dam at Vioolsdrif should be removed from consideration on the grounds that it > 75% of the impacts associated with that option were severe or higher.

The rating provided here is preliminary, based on expert option and it obviously open to some discussion and disagreement on the details. It is thus essential that additional consultations, data collection and evaluation be undertaken to assess 1) the validity of the information provided here and 2) whether other, as yet unidentified impacts (such as water quality effects linked to the geological setting) may be associated with a particular option. In this regard, key areas requiring further input include:

- Comprehensive reserve determinations. Not only will these provide much needed clarity on the ecological water requirements for the river and estuary, they will also allow time for

[2] Related to entrapment of invertebrates, plant disseminules, debris, etc.

the specialists to investigate the rivers in the vicinity of the proposed dams in some detail (something which was not possible in this study).

- The likely water quality profiles of various dam options, particularly with regard to their potential for algal growth, which will affect the reserviours theselves and the downstream environment.
- The riverine habitat (including the riparian zone) likely to be inundated, and its availability outside of the various inundation zones.

3.5 POTENTIAL IMPACTS ASSOCIATED WITH CONSTRUCTION

Most construction impacts are related to water quality, for instance soil erosion, spillage of chemicals, seepage of dirty construction water and inadequate facilities to cope with sanitary waste from construction workers. However, water quantity impacts also occur, and the need to maintain baseflows, and institute a predetermined environmental flow during the construction phase is particularly important.

3 DISCUSSION AND SUMMARY

Rivers are interconnected wholes. Impacts that affect one component of the ecosystem do so through their affect on other components of the riverine ecosystem, for instance, reduced habitat availability or quality, fragmentation of the river system or loss of invertebrates will affect fish populations. Changes in the abundance or species composition of fish communities will, in turn, affect the abundance and distribution of other animals and plants, both riverine and terrestrial, as food supplies or preferences change and competition for food and space changes.

Some of the potential impacts of the proposed dams on the lower Orange River can be ameliorated, through for instance, provision of environmental flows, fish ladders and careful positioning of outlet structures, but others cannot. The general picture painted by the ecologists in this study is of a river that has increasing had the natural checks and balances that controlled (and promoted) the distribution of species removed. In their place, a more stable, more predictable and less flexible regime has paved the way for the successful proliferation of those species best able to adapt to it, at the expense of other, more sensitive or specialised, species. More abstraction, impounding and artificial management of the system is likely to exacerbate these trends, bringing along with it the threats of species extinction and the costs of coping with the resultant problems. In summary, these include:

- pest species, both fauna and flora;
- poor water quality;
- toxic algal blooms; and
- increased flood damage.

Finally, the assessment presented here suggests that:

- all of the proposed options will have a detrimental impact on the riverine ecosystem.
- a dam at Boegoeberg would have the least impact relative to the other options;
- a dam at Vioolsdrif would have the most impact relative to the other options, particularly the options with the dam walls of 44 and 55 m.
- dams with lower dam walls have relatively less impact than those with higher dam walls.

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APPENDIX 1: SUMMARY OF ECOLOGICAL ISSUES PERTAINING TO THE CONSTRUCTION OF LARGE DAMS IN THE LOWER ORANGE RIVER – from Task 8.3.

Location	**Boegoeberg**	**Komsberg**	**Vioolsdrif**
Size	15% MAR (60 m)	15% MAR (60 m)	15% MAR (60 m) - reregulation dam c. 30 m.
Access road	Done	Difficult.	Difficult.
Purpose	Large dams: Save operational loses and storage.	Re-reg to save operational losses (300 MCM). Large dams: Save operational loses and storage.	Originally for managing the mouth of the Orange River. - not for river management. Re-reg to save operational losses (300 MCM). Large dams: Save operational loses and storage.
Ranking from an ecological perspective	Best option.	Second worse option.	Worst option.
Inundation	Orange River Broken Veld - rare. But relatively small proportion affected? Check. Asbestos mine dumps may have to be moved.	Shortest inundation - steepest but highest wall. 60 m to lower lip of lower falls. Narrow rocky gorge - half gorge structure inundated - aesthetic loss.	
Substrate	What is the nutrient state of the geology?		
Water quality	Stratification will need to be checked to sort out Temps - can cause shocks to d/s biota - already occur at VDKloof.		
	Eutrophication		
Geomorphology	Sand banks being pushed downstream. Nat processes of scouring erosion and deposition altered - through loss of Q and loss of sediments. Armouring d/s. Change in gradient - gravel and sand deposit. Fine grains stay in suspension. Gravel need to be introduced to river if flow not competent to transport - gravel will not move downstream and d/s becomes gravel poor. Bar will not form d/s as they require gravel first. Further d/s reaches will become coated in silt and any floods will disturb silt. Flood 99-00 in Fish influenced Richtersveld - substrate composition almost same as OR. Both prone to deliver clay material.		
			Reregulation dam best option BUT all bad.
Algae	Create a nursery for algal growth - noxious algae. Good bear in mind recent change in Vaal (8-10 yrs) Othisitoria - spimopsis have moved into the system - very dangerous. Indicates significant of eutrophication and loss of stabilising buffers. Typical of over regulated river - virtually converted to longitudinal dam. Useful life fairly short ito WQ. Decrease in sedimentation results in increased light penetration and increased algae. Dams will capture poor flood waters from Vaal.		
Other			Copper mine proposed in south of Nam - but if big flood comes will flush the effluent from copper mine into the Vioolsdrif dam. Better to have dam situated higher - in this particular context. Very bad for algae.
Vegetation		Orange River represents a very important strip oasis	

Location	**Boegoeberg**	**Komsberg**	**Vioolsdrif**
	Raising where infrastructure - etc. least destructive. Already Prosopis invested. Least damaging re vegetation.	Impinges on Augrabies. Rocky gorge - starving of sediments. The expectation is that the sections of river downstream of Augrabies that are in relatively good condition will decline in condition.	Upstream fairly natural and effect Richtersveld d/s. Despite release - partly because of sediments partly lack of variability. Worst.
		Near to a natural barrier. Small fish species cannot more past Augrabies.	Will split range of endemic fish (***Barbus hospus***).
Fish	Create haven for alien fish - carp and ***Tilapia mosambicensis***	Upstream barrier	
		Most diverse fish assemblage in whole OR system!!	
		Situating the dam further downstream would be better from fish perspective.	
Invertebrates	First choice. Because already impacted. Already cause invasions of snails. D/s to Upington river cannalised and very limited functioning (ecologically) - could also trap poor water from Vaal if did come.	Last choice. One of the few areas left in river in reasonably good nick. River structure very sensitive to flow / sediment changes and ecosystem functions fairly unique. Proposed transfrontier park. Damaras Farm has already been bought by Augrabies NP.	Not much happening from functioning point of view - fairly depaupaurate. Snags etc provide most of habitat.
Bilharzia		Possible threat because ToC higher.	Possible threat because ToC higher.
Environmental Flows			
Size	Less than 1 MAR less damage - possibly look at pd MAR though.		
	Boegoeberg and Komsberg - divide river into three equal section - beneficial for management of the river.		
Opportunities	Best option - have advantage of putting in structure, which can used to manage the EF. Will provide opportunities for managing lower river. Also to regulate flows for black fly control - further d/s less opportunity for doing that. But this will be limited by irrigation infrastructure – pumps, etc.	Ability to control floods increases upstream - but capacity of dams too small to control damaging floods.	
		Can release large flood required by estuary but will armour / mess up the lower section, which are not as damaged. Costs of release structures are high and they require testing, which damages the downstream riverine ecosystem. Difficult to buffer impact.	
Constraints			Only can be useful for OR Mouth management.