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| **PROJECT NAME** | **:** | PRE-FEASIBILITY STUDY INTO MEASURES TO IMPROVE THE MANAGEMENT OF THE LOWER ORANGE RIVER AND TO PROVIDE FOR FUTURE DEVELOPMENTS ALONG THE BORDER BETWEEN NAMIBIA AND SOUTH AFRICA |
| **REPORT TITLE** | **:** | Dam Development Options and Economic Analysis – Volume 1 & Volume 2 (Appendices) |
| **AUTHORS** | **:** | R A Alexander<br>D I van Wyk |
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Submitted on behalf of the Project Team by:

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**PERMANENT WATER COMMISSION**

Directorate of Project Planning

Approved for the Planning Committee of the Permanent Water Commission by:

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# LIST OF REPORTS

| TITLE | REPORT NUMBER | | |
|---|---|---|---|
| | DWAF RSA | DWA Namibia | LORC (NS) |
| Main Report | PB D000/00/4703 | 400/8/1/P-13 | 3749/97331 |
| Legal, Institutional, Water Sharing, Cost Sharing, Management and Dam Operation | PB D000/00/4603 | 400/8/1/P-10 | 3692/97331 |
| Specialist Report on the Environmental Flow Requirements - Riverine | PB D000/00/4503 | 400/8/1/P-07 | 3519/97331 |
| Specialist Report on the Determination of the Preliminary Ecological Reserve on a Rapid Level for Orange River Estuary | PB D000/00/4503 | 400/8/1/P-08 | 3663/97331 |
| Water Requirements | PB D000/00/4202 | 400/8/1/P-02 | 3486/97331 |
| Hydrology, Water Quality and Systems Analysis (Volume A) | PB D000/00/4303 | 400/8/1/P04 | 3736/97331 |
| Hydrology, Water Quality and Systems Analysis (Volume B) | PB D000/00/4303 | 400/8/1/P-03 | 3485/97331 |
| Water Conservation and Demand Management | PB D000/00/4903 | 400/8/1/P-12 | 3487/97331 |
| **Dam Development Options and Economic Analysis – Volume 1** | **PB D000/00/4403** | **400/8/1/P-05** | **3484/97331** |
| Dam Development Options and Economic Analysis – Volume 2 (Appendices) | PB D000/00/4403 | 400/8/1/P-05 | 3484/97331 |
| Environmental Assessment of the Proposed Dam Sites on the Orange River | PB D000/00/4503 | 400/8/1/P-06 | 3873/97331 |
| Vioolsdrift/Noordoewer Joint Irrigation Scheme: Assessment of Viability | PB D000/00/4803 | 400/8/1/P-11 | 3525/97331 |
| Public Consultation | PB D000/00/4503 | 400/8/1/P-09 | 3869/97331 |
| Inception Report | PB D000/00/4102 | 400/8/1/P-01 | 3365/97331 |

# *EXECUTIVE SUMMARY*

## *PURPOSE AND CONTENT OF THIS REPORT*

*The Pre-feasibility Study into measures to improve the management of the Lower Orange River (LORMS) has been split into a number of main tasks, of which the Dam Development Options is one. The Dam Development task has, in turn, been split into the following sub-tasks:*

- *4.1a: Identification of dam sites*
- *4.1b: Pre-screening of development options*
- *4.1c: Development of design and cost criteria*
- *4.1d: Preliminary designs and cost estimates*
- *4.1e: Operating rules*
- *4.1f: Areas of inundation*
- *4.1g: Border demarcation*
- *4.2: Economic analyses*
- *4.3: Water sharing, cost sharing and dam operation*

*This report covers all of the above tasks with the exception of the following tasks which will be reported on separately:*

- *4.1e: Operating rules*
- *4.1g: Border demarcation*
- *4.3: Water sharing, cost sharing and dam operation*

*This report therefore includes:*

- *Revised and updated dam design component-sizing criteria, and dam costing criteria.*
- *Details of additional dam sites that were identified on the Orange River along the common border.*
- *Details of a dam site that was identified on the Fish River.*
- *Details of pre-screening factors that were applied in making an initial elimination of dam sites.*
- *Details of the various pre-screening processes in which dam development options were eliminated from further consideration.*
- *A list of more promising dam sites that were considered in more detail.*
- *Comparison of the best dam development option with the previously-identified Vioolsdrif and Boegoeberg Dam sites.*

## *DEVELOPMENT OF DESIGN AND COST CRITERIA*

*The study commenced with a review of the 'Guidelines for the preliminary sizing, costing and engineering economic evaluation of planning options' developed during the Vaal Augmentation Planning Study (VAPS) for the South African Department of Water Affairs and Forestry (DWAF).*

*The component sizing criteria were reviewed and modified where deemed necessary. In particular, the sections on flood determination for the various dam types were rewritten due to inconsistencies in the terminology and presentation in the VAPS guidelines. The sections on foundation grouting were rewritten to be consistent between the various dam types.*

*The cost models were updated by utilising contract prices, with appropriate escalation, for the recently constructed Maguga, Mohale, Inyaka and Bivane (Paris) Dams, as well as the Matsoku Weir.*

## *IDENTIFICATION OF DAM SITES*

*The purpose of this sub-task was to mark up all the relevant options identified in the Orange River Development Project Replanning Study (ORRS) on the 1:50 000 topographical maps, to identify any new options to the west of the 20° longitude along the common border between South Africa and Namibia and to identify a potential dam site on the Fish River.*

### ***Options Upstream of the Common Border***

*In the ORRS, eight possible development options upstream of the common border were identified and evaluated. No new sites were identified in this study. These development options are listed in the* ***Table 1****.*

***Table 1: Development Options Identified in the ORRS Upstream of the Common Border within the LORMS Study Area***

| Development Option | Location |
|---|---|
| New Boegoeberg Dam | ~ 1 km downstream of existing Boegoeberg Dam |
| Hospital Dam | ~ 20 km upstream of Prieska |
| Lanyonvale Dam | ~ 60 km downstream of Douglas |
| Torquay Dam | ~ 47 km downstream of Hopetown and ~ 35 km upstream of Vaal/Orange Confluence |
| Hereford Weir | ~ 35 km downstream of Hopetown |
| Eskdale Weir | ~ 15 km downstream of Hopetown |
| Elandsdraai Dam | ~ 15 km upstream of Hopetown |
| Havenga Bridge Dam | ~ 15 km downstream of Vanderkloof Dam |

***Options along the Common Border***

*All the potential dam sites along the common border that were identified in this study, as well as those identified in the ORRS, are listed in the **Table 2**.*

***Table 2: Development Options Identified along the Common Border***

| Name of Dam Site | Appendix | Approximate Chainage (1) (km) | Comment |
|---|---|---|---|
| Kabies | C2 | 148 | Identified in ORRS |
| Grootpens A | C3 | 173 | |
| Grootpens B | C3 | 177 | |
| Aussenkehr | C3 | 223 | Identified in ORRS |
| Vioolsdrif A | C4 | 303 | Identified in ORRS |
| Vioolsdrif B | C4 | 318 | Identified in ORRS |
| Vioolsdrif C | C4 | 322 | Identified in ORRS |
| Vioolsdrif D | C4 | 327 | |
| Kambreek | C6 | 433 | Identified in ORRS |
| Coboop A | C6 | 465 | |
| Coboop B | C6 | 475 | |
| Coboop C | C6 | 479 | |
| Beenbreek | C7 | 512 | |
| Yas | C7 | 542 | |
| Komsberg | C7 | 580 | |

*Note*

1) *The chainage is the approximate distance measured along the Orange River, starting at the mouth of the river.*

***Options on the Fish River***

*A site was selected at Koubis, immediately upstream of the Ai-Ais Nature Reserve, as being representative of typical sites in the area to provide reservoir characteristics for input into the hydrological model of the Lower Orange River (LOR). Initial runs of the hydrological model indicated that a dam on the Fish River would not be attractive in the regional context and no further investigations was carried out.*

*ENVIRONMENTAL CONSIDERATIONS AND EXISTING INFRA-STRUCTURE*

*Before the pre-screening of the development options could be undertaken, background data had to be obtained on the environmental considerations associated with, as well as the existing infrastructure that could be affected by the proposed options. The following pre-screening factors were investigated:*

- *Reaches of ecological importance and sensitivity;*
- *Areas of archaeological and historical interest;*
- *Cultivated land that could be inundated due to dam development;*
- *Land over which various mining and prospecting licenses had been issued, and for which the licensees would have to be compensated for areas that would be inundated;*
- *Towns and villages that would be inundated;*
- *National parks;*
- *Powerlines across the river, that would possibly have to be re-routed; and*
- *Roads and bridges across the river that would possibly have to be re-routed.*

***Ecological Issues***

*The following issues of concern were identified:*

- *The natural distribution of the median monthly flows in the LOR, which have already been significantly altered by the Gariep and Vanderkloof Dams, may be distorted even more.*
- *A new impoundment will have physico-chemical effects such as stratification and riverbed degradation.*
- *It will also impact on the riverine biota, such as vegetation, freshwater invertebrates and freshwater fish species.*
- *Unique river reaches such as inland deltas will be affected.*

***Areas of Archaeological and Historical Interest***

*The following conclusions were made on the above topic:*

- *Extrapolating what is known from localities to the east and west of the study area, it could reasonably be predicted that any potential dam site within the study area will have heritage impacts.*
- *The Richtersveld is archaeologically rich and inundation of the river valley will have an impact in the immediate vicinity of the river.*
- *A preliminary field assessment will be necessary before any idea of the kinds of impacts that may be involved, can be gained.*
- *Some detailed archival research may also be necessary to identify places of conflict as well as help establish the significance of any sites found.*

***Cultivated Land***

*Presently cultivated areas along the common border, as well as potentially irrigable areas along both the South African and Namibian sides of the river were recorded during the course of the investigation into water demand and management.*

***Mining and Prospecting Licenses***

*Mining and prospecting licenses have been issued over much of the reach of the common border and mining for diamonds, pegmatites, fluorspar and tungsten had taken place in the area. It is not possible to quantify the cost of compensation for the loss of prospecting and mining licenses, or differentiate between the licenses. The cost of compensation has therefore been assumed to be equal for all sites.*

***Roads and Bridges***

*Three bridges cross the Orange River along the common border, namely at Oranjemund/Alexander Bay, Vioolsdrif/Noordoewer and Onseepkans. The extent to which these bridges and their approaches will be inundated by any dams constructed on the river will depend on the full supply levels of the dams.*

***Towns and Villages***

*Two towns, namely Goodhouse and Onseepkans, could be partly or wholly inundated by water impounded by new dams constructed at the Vioolsdrif and Kambreek sites.*

***National Parks***

*The Ai-Ais Nature Reserve in Namibia and the Richtersveld Nature Reserve and Augrabies Falls National Park in South Africa border on the Orange River and may therefore be partly inundated by dam construction along the common border.*

***Powerlines***

*Four powerlines that cross the Orange River along the common border have been identified, namely at Oranjemund, Rosh Pinah, Noordoewer and on the Farm Kabis.*

## *PRE-SCREENING OF DEVELOPMENT OPTIONS*

***Options Upstream of the Common Border***

*The ORRS concluded that most of the initial development options considered in the Orange River Basin could be eliminated from further consideration on financial, social, engineering or environmental grounds. Only a small number of options remained as possible future developments, however, it was not possible to make firm recommendations at that stage.*

*In all of the remaining options, it was considered necessary to create some form of operational storage along the Orange River at either Vioolsdrif or Boegoeberg. Both options had similar Unit Reference Values (URVs) and it was not possible to eliminate either of them during the Pre-feasibility Phase of the ORRS.*

*In the LORMS, no reason could be found to differ from the conclusion of the ORRS that the most feasible option for the construction of a new dam upstream of the common border is the New Boegoeberg Dam.*

***Options along the Common Border****:*

*A preliminary pre-screening was done on the dam sites that were identified earlier, with a view of eliminating those options that were clearly flawed from engineering, social or environmental considerations. The remaining options, namely Vioolsdrif A (as representative of the four sites), Yas and Komsberg were subjected to a cost analysis and evaluation against the pre-screening criteria. The comparison between the pre-screening cost and the reservoir capacities is shown in the* ***Figure 1****.*

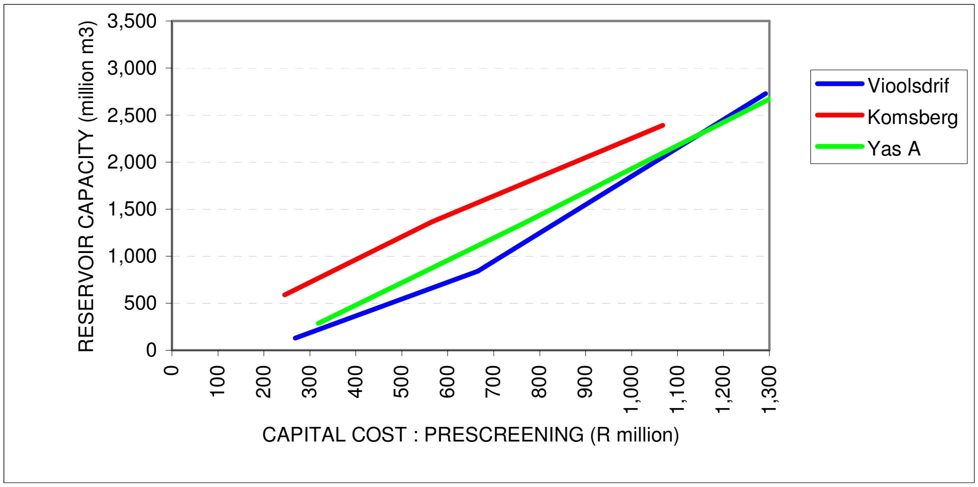


***Figure 1: The Comparison between the Pre-screening Cost and the Reservoir Capacities***

***Capital Cost (comparative) of Dam Construction versus Reservoir Capacity***

*The evaluation against the pre-screening criteria is shown in the **Table 3**.*

### *Table 3: The Evaluation against the Pre-screening Criteria*

| **Pre-screening Factor** | **Dam Site** | | |
|---|---|---|---|
| | **Vioolsdrif A** | **Yas** | **Komsberg** |
| ***Site considerations*** | | | |
| *Topography of site and basin* | *Moderately good dam site* | *Good dam site* | *Very good dam site - narrow valley* |
| *Geological conditions* | *Only the Vioolsdrif Dam site was investigated (in the ORRS study) and geological conditions can therefore not be used as a factor for pre-screening purposes.* | | |
| *Construction materials & borrow areas* | *Only the Vioolsdrif Dam site was investigated (in the ORRS study) and this pre-screening factor can therefore not be used as a factor for pre-screening purposes.* | | |
| *Storage capacity potential* | *Potential storage capacities all exceed the maximum volume that can be utilized effectively* | | |
| *Small re-regulating dam or large storage dam* | *All sites are suitable for either a small re-regulating dam, or a larger storage dam.* | | |
| *Design floods & spillway arrangements* | *Design floods similar due to relatively great distance to main catchment areas* | | |
| | *Mass concrete overflow* | *Mass concrete overflow plus possible by-wash* | *Mass concrete overflow* |
| *Seismic characteristics* | *All of the sites are situated in a low seismic risk area.* | | |
| *River diversion during construction* | *For pre-screening purposes only mass concrete gravity dams were considered, and river diversion considerations are therefore identical.* | | |
| *Considerations to site establishment* | *Not considered during pre-screening.* | | |
| *Access roads* | *Access is difficult due to steep valley sides* | *1:50 000 maps do not indicate roads in the immediate vicinity of the dam sites* | |
| | | | |
| ***Contribution to the system yield*** | *Considered to be similar for all sites due to negligible additional inflow from catchment areas in the vicinity of these dams sites.* | | |
| ***Social and environmental impacts*** | | | |
| *Potential social impacts* | *Social impacts of the individual sites were not investigated, but the social impacts of the sites should not differ from one another significantly.* | | |
| *Potential environmental impacts* | *Considered relatively low* | *Inundation of parts of the Augrabies Falls National Park* | |

| Pre-screening Factor | Dam Site | | |
|---|---|---|---|
| | Vioolsdrif A | Yas | Komsberg |
| Proximity / location to major centres | ~ 20 km from Vioolsdrif / Noordoewer | ~ 60 km from Onseepkans | ~ 90 km from Onseepkans |
| International borders | Situated on the border between Namibia and South Africa. | The above dams and other dams constructed in the vicinity will have a lesser effect on international borders as water pushes up past 20º longitude. | |
| Possibility of hydro-power generation | There is the possibility of hydro-power generation at all sites investigated. | | |
| Proximity to powerlines | 20 km (line at Vioolsdrif / Noordoewer) | 200 km (line on farm Kabis) | 240 km (line on farm Kabis) |
| Flooding of existing infrastructure | No flooding of major infrastructure | | |
| Flooding of irrigation areas: existing and potential | Potential flooding of irrigation areas in the vicinity of the river. | | Smaller irrigation areas flooded |
| Flooding of mining and prospecting license areas | On Namibian side of border, all dams flood areas over which mining and prospecting licenses have been issued. Not much difference between one dam and the other. | | Smaller areas flooded |
| Flooding of areas of archaeological importance | The conclusions of the desk study are that not many detailed investigations had been carried out to date and further investigations would have to be carried out for particular sites in the case of dam construction. | | |
| Sedimentation rate | The difference is sedimentation rates between the different sits was not investigated but is not considered to be significant enough to influence a choice between the sites. | | |
| Potential effects on water quality | The difference on the effects on the water quality between the different sites was not investigated, but is not considered to be significant enough to influence a choice between the sites. | | |
| | | | |
| **Cost** | Moderate cost | Similar to Vioolsdrif | Lowest cost of all sites |

### *Discussion of Pre-screening Analysis*

*Vioolsdrif A*

*The dam site is situated close to existing infrastructure, but access to the site will be difficult due to the steep valley sides. The dam will inundate areas over which mining and prospecting licenses have been issued, over most of the distance that the impounded water pushes up the river.*

*Yas*

*This dam site is situated approximately 54 km downstream of the border at 20º longitude. As in the case of the Komsberg site, much of the water stored by the dam will be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure, or powerlines. A dam at this site would have a similar cost to dams at the Vioolsdrif sites.*

*Komsberg*

*This dam site is situated approximately 7 km downstream of the border at 20° longitude. Most of the water stored by the dam will therefore be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park, which is situated along the northern side of the river. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure, or powerlines.*

*Based on the 1:50 000 mapping, this site was found to be the most economical site along the common border for the construction of a dam for the range of reservoir capacities under consideration. However, the extent of the inundation of the Augrabies Falls National Park remained of concern.*

***Conclusions***

*Based on the pre-screening the following conclusions were made:*

- *The Yas Dam site does not offer any significant cost benefits over the Vioolsdrif site and will inundate parts of the Augrabies Falls National Park. It was therefore excluded from further analysis.*
- *From a capital cost point of view (as defined in this report), the Komsberg site is more cost-effective than the Vioolsdrif site for the construction of either a smaller re-regulating dam or a larger dam to improve the yield of the system. The allowable inundation of the Augrabies Falls National Park, however, still had to be determined.*

*The net result of the pre-screening was that both the Viooldrif A and the Komsberg Dam sites were taken to a Decision-making Workshop.*

## *ASSESSMENT OF PRE-SCREENED DEVELOPMENT OPTIONS*

*In the pre-screening process the number of dam sites that could possibly be carried forward to the preliminary design stage was reduced to the following sites:*

*Upstream of 20° longitude (i.e. upstream of the common border):*

- *New Boegoeberg Dam*

*Downstream of 20° longitude (i.e. along the common border):*

- *Vioolsdrif Dam*
- *Komsberg Dam*

*These three possible options were investigated in order to make more accurate cost estimates, determine yields and assess benefits and impacts. The options were then evaluated at a Decision-making Workshop by a team consisting of the Client, selected stakeholders and the Consultant.*

*Prior to the workshop, the following activities were carried out on the three dams:*

- *A yield analysis was carried out in order to determine the required storage capacities for specified yields.*
- *A sedimentation analysis was carried out on the New Boegoeberg and Vioolsdrif sites in order to estimate the sedimentation volumes.*
- *A financial analysis was carried out in order to determine the unit reference values of dams of various storage capacities.*

*The pertinent data for the New Boegoeberg, Vioolsdrif and Komsberg Dam sites is summarised in **Table 4**.*

***Table 4: Pertinent Values for the Preferred Sites for Re-regulating Dams***

| | New Boegoeberg | Vioolsdrif | Komsberg |
|---|---|---|---|
| Proposed dam size (million $m^3$) | 163 | 260 | 260 |
| Unit reference value (@ 8%) (R/$m^3$) | 0,35 | 0,26 | 0,24 |
| Saving in operational losses (million $m^3$/a) | 62 | 170 | 126 |

*At the workshop, it was decided that the Vioolsdrif and Komsberg Dam sites were preferred to the New Boegoeberg Dam site for the following reasons:*

- *Significantly lower unit reference values; and*
- *Significantly larger saving in operational losses.*

*Due to the fact that dams for all heights under consideration at the Komsberg site would inundate parts of the Augrabies Falls National Park, it was decided that the Komsberg site should not be considered unless there were significant cost advantages. The cost estimates of the Vioolsdrif and New Boegoeberg Dam sites* *had been done on 1:10 000 mapping with 5 m contours, whilst that of the Komsberg Dam site was done on 1:50 000 mapping with 20 m contours. It was therefore decided that 1:10 000 mapping should also be prepared for the Komsberg site. Based on this mapping, the quantities for the Komsberg Dam site were re-calculated. The URV for a dam with a capacity of 260 million $m^3$ increased to R0.28/$m^3$.*

*The river bed levels downstream of the Augrabies Falls were also checked by using the Digital Elevation Models (DEMs) of the area. The river bed level at the Komsberg Dam site is at approximately RL 430.8 m. Above a full supply level (FSL) of approximately RL 432 m water will start pushing up into the Augrabies Falls National Park, and the rapids downstream of the Falls will start to be inundated at levels above RL 450 m. The FSL for the proposed re-regulating dam will be at approximately RL 446m.*

*After the workshop, field visits were made to the Vioolsdrif and Komsberg areas in order to carry out a vegetation study and ecological and archaeological assessments.*

*The improved costs, the results of the vegetation and archaeological studies, the ecological assessment, as well as other factors that needed to be considered in assessing the options were presented to the Client.*

*A summary of the above assessments is presented in **Table 5**.*

***Table 5: Summary of Assessment of Vioolsdrif and Komsberg Options***

| **Dam Sites** | **Vioolsdrif** | **Komsberg** |
|---|---|---|
| **Issues** | | |
| Potentially serious implications of any raising of the dam in future | None | Inundation of the rapids downstream of the Augrabies Falls. |
| Impact on Augrabies Falls and National Park | None | Dam basin inside the Park and potential sediment and back water affects in rapids |
| Saving in operational losses (million $m^3$/a) | 170 | 126 |
| Ecological | Would have the most impact relative to the other options. | Would have a lower impact than the Vioolsdrif Dam option. |
| Archaeological | Would have the greater impact on archaeological remains. | Would have a lesser impact on archaeological remains than Vioolsdrif. |
| Vegetation | Would overall affect a less developed stretch of riparian landscapes and habitats. | Would affect large stretches of relatively pristine riparian woodlands, though interrupted by agricultural developments. |
| Unit reference values (R/$m^3$) | 0.26 | 0.28 |

*On the basis of these factors, it was decided that the development of a re-regulating dam at the Vioolsdrif Dam site was preferred to the Komsberg Dam site.*

## *PRELIMINARY DESIGN*

### ***Dam Site***

*The preliminary design was based on the Vioolsdrif A Dam site due to the smaller cross-sectional area than the other three sites and to facilitate comparison with the ORRS work.*

### ***Available Mapping***

*All the work in the ORRS at the Vioolsdrif Dam sites was based on the 1:50 000 topo-cadastral maps of the area. The 1:50 000 mapping was retained to compile the storage capacity curve for the site, but survey plans at a scale of 1:10 000 with 5 m contours were prepared from aerial photography for the dam site.*

### ***Flood Determination***

*In terms of the Guidelines for Sizing of Mass Concrete Dams, the flood magnitudes were based on the Regional Maximum Flood (RMF) concept. The Safety Evaluation Discharge (SED) was calculated to be 26 300 $m^3$/s and the Recommended Design Discharge (RDD) 14 250 $m^3$/s.*

*The diversion flood for a concrete dam is based on the 1:10 year recurrence interval (RI) flood, which was estimated to be 3 000 $m^3$/s.*

*For the preliminary design a total freeboard of 10 m was used.*

### ***Spillway Design***

*Due to the high flood magnitudes that need to be passed over the dam, the complete base width of the valley of 375 m will be used as spillway.*

### ***Dam Size***

*The preliminary design was done for a dam with the following parameters:*

- *Total storage capacity* — *260 million $m^3$*
- *Allowance for sedimentation* — *150 million $m^3$ (from ORRS)*
- *Live storage capacity* — *110 million $m^3$*
- *Wall height to (NOC)* — *35.1 m*

| | |
|---|---|
| • *Wall height to FSL* | *25.1 m* |
| • *River bed level* | *RL 176.4 m (approximately)* |
| • *FSL* | *RL 201.5 m* |
| • *NOC* | *RL 211.5 m* |
| • *Total crest length* | *485 m* |

***Dam Type Selection***

*Due to the large design floods the complete river section must be utilised as a spillway. A concrete gravity dam was therefore considered to be the only type of dam suitable for the site. Due to its inherent lower costs a rollcrete dam was chosen for the preliminary design.*

***Outlet Works***

*The estimated monthly demand figures for a re-regulating dam vary from a minimum of 2.3 $m^3$/s in June to 11.8 $m^3$/s in January. Two 2 m diameter pipe stacks are allowed for with 1.8 m diameter inlets at 7 m centres. With a normal operating flow velocity of 4 m/s each pipe stack can discharge 12.6 $m^3$/s. The water will be discharged through 1.2 m diameter sleeve valves.*

*The estimated maximum environmental flow requirement is 400 $m^3$/s in February. Whilst it can be expected that the dam would normally overflow during this time, allowance has been made for the installation of two 3.0 m wide by 3.5 m high radial gates to act as bottom outlets.*

***Flood Diversion Works***

*The first stage of the river diversion will consist of an approximately semi circular 8 m high rollcrete cofferdam that will be built on the left hand side of the river valley to close off 250 m of the river channel. Culverts will be installed in the rollcrete for diversion purposes during the second stage.*

*The second stage will require 15 m high rollcrete upstream and downstream cofferdams to link the right flank with the already completed dam.*

***Access Roads and Site Establishment***

*Access to the site is difficult due to the steep valley sides. There is also no space available at the dam site for site establishment. For the purposes of the preliminary design a gravel access road on the left bank was costed. The access road will be* *prone to frequent flooding unless it can be located above approximately 10 m above the river bed level.*

***Dam Raising***

*According to the systems analysis, the projected future downstream demands would require a live storage volume of 1 500 million $m^3$. The 50-year sediment volume was estimated at approx 600 million $m^3$. The total storage volume would be 2 100 million $m^3$ at a spillway height of 54.6 m. This would require a 29.5 m raising of the re-regulating dam.*

*The re-regulating dam can be raised by adding rollcrete on the downstream side. In order to allow for such an eventuality the Outlet Works were moved 24 m downstream in the preliminary design. The Intake Tower will be extended vertically whilst adding further intakes to the pipe stacks.*

***Hydropower Potential***

*The available flow rate for hydropower generation was taken as the monthly demand figures plus the minimum environmental flow requirement (EFR). The average flow rate over a full year was estimated at 15.4 $m^3$/s. The minimum available head is 20.3 m.*

*The maximum generating capacity is 4.2 MW. The total annual power generation was estimated at 21.3 GWh.*

*The estimated capital cost of the power station is R30 million, which allows for all civil and mechanical/electrical works up to and including the switchgear at the dam site. No allowance was made for the cost of any distribution lines. The estimated potential income is R3.4 million per annum, based on a selling rate of R0.12 per kWh and a carbon emission reduction subsidy of R0.04 per kWh.*

## *COST ESTIMATE*

*The total project cost for a rollcrete re-regulating dam at the Vioolsdrif A site at April 2004 rates is estimated to be R 561 million.*

## *ECONOMIC ANALYSIS*

*The Boegoeberg, Vioolsdrif and Komsberg sites were compared on an engineering economic basis. It firstly proved that the Vioolsdrif site is more beneficial than the Boegoeberg site for the full spectrum of capacities investigated. Initially, a re-regulating dam at Komsberg seemed more beneficial than at Vioolsdrif, but after more detailed mapping was obtained, Vioolsdrif proved to be the more economic site for the re-regulating dam.*

*The analysis proved that the re-regulating dam only will not make adequate additional yield available to serve the full demand until 2025. Additional storage on the system is required.*

*Analysis of the Vioolsdrif Dam options proved that a phased development, i.e., the future raising of the re-regulating dam, is economically more beneficial than construction to full capacity at once for the larger capacity dam. The outcome of other studies will also influence the decision if the re-regulating dam is to be raised or additional storage is to be created elsewhere in the system. It is recommended that this aspect be investigated further in the Feasibility Study.*

# TABLE OF CONTENTS

## VOLUME 1 REPORT

**EXECUTIVE SUMMARY** iii
**TABLE OF CONTENTS** xix
**LIST OF ABBREVIATIONS** xxv
**LIST OF TABLES** xxvi
**LIST OF FIGURES** xxvii

**1. INTRODUCTION ....................................................................................28**
1.1 PURPOSE AND CONTENT OF THIS REPORT ..............................................28
1.2 METHODOLOGY..........................................................................................29
1.3 PREVIOUS INVESTIGATIONS.......................................................................29
**2. DEVELOPMENT OF DESIGN AND COST CRITERIA ................................32**
2.1 INTRODUCTION ..........................................................................................32
2.2 CHANGES MADE TO THE COMPONENT SIZING CRITERIA ..........................32
2.3 CHANGES MADE TO THE COSTING MODELS ..............................................35
2.3.1 Introduction ..........................................................................................35
2.3.2 Review of Costing ..................................................................................35
**3. IDENTIFICATION OF DAM SITES.............................................................38**
3.1 PURPOSE OF SUB-TASK..............................................................................38
3.2 METHODOLOGY..........................................................................................38
3.2.1 Options Upstream of the Common Border................................................38
3.2.2 Options along the Common Border ..........................................................38
3.2.3 Options on the Fish River ........................................................................39
3.3 POTENTIAL DAM SITES IDENTIFIED ...........................................................39
3.3.1 Options Upstream of the Common Border................................................39
3.3.2 Options along the Common Border ..........................................................40
3.3.3 Options on the Fish River ........................................................................42
**4. ENVIRONMENTAL CONSIDERATIONS AND EXISTING INFRASTRUCTURE......................................................................43**
4.1 INTRODUCTION ..........................................................................................43
4.2 ECOLOGICAL IMPORTANCE AND SENSITIVITY OF THE LOWER ORANGE RIVER...........................................................................................43
4.2.1 River Flow ............................................................................................43

4.2.2 Issues of Concern in respect of Dam Construction in the Orange River Reach from 20° Longitude to the Orange-Fish River Confluence ..... 44
4.3 REPORT ON THE HERITAGE SENSITIVITY OF THE SOUTH AFRICAN SIDE OF THE ORANGE RIVER DOWNSTREAM OF 20° LONGITUDE ..... 49
4.3.1 Introduction ..... 49
4.3.2 Method ..... 49
4.3.3 Restrictions ..... 49
4.3.4 Available Information ..... 49
4.3.5 An Estimation of Sensitivity ..... 51
4.3.6 Conclusions ..... 52
4.4 REPORT ON THE HERITAGE SENSITIVITY OF THE NAMIBIAN SIDE OF THE ORANGE RIVER DOWNSTREAM OF 20° LONGITUDE ..... 53
4.5 CULTIVATED LAND ..... 54
4.6 MINING AND PROSPECTING LICENSES ..... 55
4.6.1 South Africa ..... 55
4.6.2 Namibia ..... 55
4.7 ROADS AND BRIDGES ..... 56
4.8 TOWNS AND VILLAGES ..... 57
4.9 NATIONAL PARKS ..... 57
4.10 POWERLINES ..... 58
**5. PRE-SCREENING OF DEVELOPMENT OPTIONS ..... 59**
5.1 PURPOSE OF SUB-TASK ..... 59
5.2 PRE-SCREENING FACTORS ..... 59
5.3 OPTIONS UPSTREAM OF THE COMMON BORDER ..... 60
5.3.1 Potential Development Options ..... 60
5.3.2 Cost Analysis and Economic Analysis ..... 62
5.3.3 Conclusions of the ORRS ..... 63
5.3.4 Conclusions of the Review of the ORRS ..... 64
5.4 OPTIONS ALONG THE COMMON BORDER ..... 64
5.4.1 Potential Development Options ..... 64
5.4.2 Cost Analysis ..... 65
5.4.3 Evaluation against Pre-screening Criteria ..... 67
5.4.4 Discussion of Pre-screening Analysis ..... 69
5.4.5 Conclusions ..... 70
**6. ASSESSMENT OF PRE-SCREENED DEVELOPMENT OPTIONS ..... 71**
6.1 INITIAL SELECTION ..... 71
6.2 KOMSBERG DAM SITE ..... 72

6.3 ECOLOGICAL ASSESSMENT ....73
6.3.1 Vegetation Study ....73
6.3.2 Ecological Assessment....73
6.3.3 Archaeological Assessment....74
6.4 CONCLUSIONS....74
**7. SEDIMENTATION ANALYSIS ....75**
7.1 INTRODUCTION ....75
7.2 SUMMARY OF REPORT ....75
7.2.1 Introduction ....75
7.2.2 Sediment Loads of the Orange River....75
7.2.3 Estimated Sedimentation Rates for Future Reservoirs at Boegoeberg and Vioolsdrif ....76
**8. PRELIMINARY DESIGN ....78**
8.1 VIOOLSDRIF DAM SITES ....78
8.2 AVAILABLE MAPPING ....78
8.3 GEOLOGY....79
8.4 FLOOD DETERMINATION ....79
8.4.1 Flood Magnitudes....79
8.4.2 Flood Attenuation ....80
8.4.3 Freeboard....80
8.5 SPILLWAY DESIGN ....81
8.6 DAM SIZE....81
8.7 DAM TYPE SELECTION....82
8.8 OUTLET WORKS ....82
8.9 FLOOD DIVERSION WORKS....83
8.9.1 Stage 1....83
8.9.2 Stage 2....84
8.10 ACCESS ROADS AND SITE ESTABLISHMENT ....84
8.11 DAM RAISING ....85
8.12 HYDROPOWER POTENTIAL....86
8.13 EXTENT OF INUNDATION....86
**9. COST ESTIMATE....87**
9.1 INTRODUCTION ....87
9.2 EXPLANATORY NOTES ....87
9.2.1 Clearing....87
9.2.2 River diversion....87
9.2.3 Excavation....87

9.2.4 Drilling and grouting.....87
9.2.5 Formwork.....87
9.2.6 Concrete.....88
9.2.7 Reinforcing.....88
9.2.8 Mechanical Items.....88
9.2.9 Fencing.....88
9.2.10 Preliminary Works.....88
9.2.11 Accommodation.....88
9.2.12 VAT.....89
9.2.13 Cost of Relocations.....89
9.2.14 Cost of Land Acquisition.....89
9.2.15 Allowance for Raising.....89

**10. ECONOMIC ANALYSIS.....90**

10.1 METHODOLOGY.....90
10.1.1 Calculation of URV.....90
10.1.2 Option Costs.....90
10.1.3 Option Benefit.....91
10.1.4 Demand Curve.....92
10.1.5 Existing Yield.....92
10.1.6 Discount Rate.....92
10.1.7 Implementation Date.....92
10.2 SCENARIOS.....92
10.3 ASSESSMENT OF PRE-SCREENED DAM DEVELOPMENT OPTIONS.....93
10.4 ASSESSMENT OF MANAGEMENT OPTIONS.....95
10.5 VIOOLSDRIFT DEVELOPMENT OPTIONS.....95

**11. CONCLUSIONS AND RECOMMENDATIONS.....97**

11.1 DEVELOPMENT OF DESIGN AND COST CRITERIA.....97
11.2 IDENTIFICATION OF DAM SITES.....97
11.3 ENVIRONMENTAL CONSIDERATIONS AND EXISTING INFRASTRUCTURE.....98
11.3.1 Ecological Issues.....99
11.3.2 Areas of Archaeological and Historical Interest.....99
11.3.3 Cultivated Land.....99
11.3.4 Mining and Prospecting Licenses.....99
11.3.5 Roads and Bridges.....100
11.3.6 Towns and Villages.....100
11.3.7 National Parks.....100
11.3.8 Powerlines.....100

11.4 PRE-SCREENING OF DEVELOPMENT OPTIONS ........................................100
11.4.1 Options Upstream of the Common Border ........................................100
11.4.2 Options along the Common Border ........................................101
11.4.3 Discussion of Pre-screening Analysis ........................................101
11.5 CONCLUSIONS ........................................102
11.6 ASSESSMENT OF PRE-SCREENED DEVELOPMENT OPTIONS ........................................103
11.7 PRELIMINARY DESIGNS AND COST ESTIMATES ........................................105
11.7.1 Dam Site ........................................105
11.7.2 Available Mapping ........................................105
11.7.3 Flood Determination ........................................106
11.7.4 Spillway Design ........................................106
11.7.5 Dam Size ........................................106
11.7.6 Dam Type Selection ........................................106
11.7.7 Outlet Works ........................................107
11.7.8 Flood Diversion Works ........................................107
11.7.9 Access Roads and Site Establishment ........................................107
11.7.10 Dam Raising ........................................107
11.7.11 Hydropower Potential ........................................108
11.8 COST ESTIMATE ........................................108
11.9 ECONOMIC ANALYSIS ........................................108
**12. REFERENCES ........................................110**

## VOLUME 2 : APPENDICES

**A** : Guidelines for the preliminary sizing, costing and engineering economic evaluation of planning options

**B** : Locality map

**C** : Location of potential dam sites (1:250 000 and 1:500 000 maps)

- C1 to C8: Orange River mouth to 20° longitude (including pre-screening factors)
- C9 to C12: 20° longitude to Vanderkloof Dam
- C13: Fish River
- C14: Correspondence with South African Department of Minerals and Energy

**D** : Layouts of potential dam sites (1:20 000 maps)

**E** : Cross-sections of potential dam sites

**F** : Longitudinal profile of the Orange River

**G** : Report on the sedimentation analysis

**H** : Preliminary design of Vioolsdrif Re-regulating Dam

**I** : Unit Reference Value Calculations

- I 1: Pre-screened options and scenarios
- I 2: Management options
- I 3: Vioolsdrift development options

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| Consultant | : | Lower Orange River Consultants |
| DEM | : | Digital Elevation Model |
| DWAF | : | Department of Water Affairs and Forestry |
| EFR | : | Environmental Flow Requirement |
| FSL | : | Full supply level |
| LORMS | : | Lower Orange River Management Study |
| LOR | : | Lower Orange River |
| MAR | : | Mean Annual Runoff |
| MOL | : | Minimum Operating Level |
| NOC | : | Non Overspill Crest |
| ORRS | : | Orange River Development Project Replanning Study |
| ORS | : | Orange River System |
| RDD | : | Recommended Design Discharge |
| RI | : | Recurrence Interval |
| RL | : | Reduced Level |
| RMF | : | Regional Maximum Flood |
| SED | : | Safety Evaluation Discharge |
| ToR | : | Terms of Reference |
| URV | : | Unit Reference Value |
| VAPS | : | Vaal Augmentation Planning Study |
| NPV | : | Nett Present Value |
| $R/m^3$ | : | Rand per cubic meter |
| $c/m^3$ | : | Cent per cubic meter |
| WC & DM | : | Water Conservation and Demand Management |

# LIST OF TABLES

Table 2.1: Embankment Dams: Sizing Guidelines ....33
Table 2.2: Mass Concrete Dams: Sizing Guidelines....34
Table 3.1: Development Options Identified in the ORRS Upstream of the Common Border within the LORMS Study Area ....40
Table 3.2: Development Options Identified along the Common Border ....40
Table 4.1: Key Freshwater Fish Species Expected to be affected by Dam Construction in the LOR Stretch between 20º Longitude and the Orange-Fish Confluence ....46
Table 4.2: River Reaches in the Orange River Stretch 20º Longitude to the Orange-Fish Confluence considered to be of Ecological Importance....48
Table 4.3: South African Side of the Orange River: Sites of Historical and Archaeological Interest....51
Table 4.4: Mining and Prospecting Licenses Issued....56
Table 4.5: Bridges across Orange River along the Common Border....56
Table 4.6: Locations of Towns and Villages ....57
Table 4.7: Locations of National Parks that may be affected by Dam Construction along the Common Border ....57
Table 4.8: Locations of High-voltage Powerlines Crossing the Orange River along the Common Border....58
Table 5.1: Details of Development Options Identified in the ORRS Upstream of the Common Border....61
Table 5.2: Single Dam Development Options considered in the Pre-feasibility Phase of the ORRS....63
Table 5.3: Potential Dam Sites identified along the Common Border ....64
Table 5.4: Pre-screening....68
Table 6.1: Pertinent Values for the Preferred Sites for Re-regulating Dams....72
Table 6.2: Summary of Assessment of Vioolsdrif and Komsberg Options....74
Table 7.1: Estimated 50-year Sediment Volumes for Storage Reservoirs at Vioolsdrif and Boegoeberg ....77
Table 8.1: Calculation of Freeboard....80
Table 10.1: Assessment of Dam Development Options ....94
Table 10.2: Water Conservation and Demand Management Options ....95
Table 10.3: Vioolsdrif Dam Development Options....96
Table 11.1: Pertinent Values for the Preferred Sites for Re-regulating Dams....104
Table 11.2: Summary of Assessment of Vioolsdrif and Komsberg Options....105

# LIST OF FIGURES

Figure 5-1: Capital Cost (Comparative) of Dam Construction versus Dam Height ................66
Figure 5-2: Reservoir Capacity versus Dam Height ............................................................66
Figure 5-3: Capital Cost (Comparative) of Dam Construction versus Reservoir Capacity ..........................................................................................................67
Figure 10-1: Benefit of Vioolsdrif Re-regulating Dam Option ............................................91
Figure 10-2: Plot of Yield for a Scenario..............................................................................93
Figure 11-1: Capital Cost (Comparative) of Dam Construction versus Reservoir Capacity ..........................................................................................................101

# 1. INTRODUCTION

## 1.1 Purpose and Content of This Report

The Pre-feasibility study into measures to improve the management of the Lower Orange River (LORMS) has been split into a number of main tasks, of which the Dam Development Options is one. The Dam Development task has, in turn, been split into the following sub-tasks:

- 4.1a: Identification of dam sites
- 4.1b: Pre-screening of development options
- 4.1c: Development of design and cost criteria
- 4.1d: Preliminary designs and cost estimates
- 4.1e: Operating rules
- 4.1f: Areas of inundation
- 4.1g: Border demarcation
- 4.2: Economic analyses
- 4.3: Water sharing, cost sharing and dam operation

This report covers all of the above tasks with the exception of the following tasks which will be reported on separately:

- 4.1e: Operating rules
- 4.1g: Border demarcation
- 4.3: Water sharing, cost sharing and dam operation

This report therefore includes:

- Revised and updated dam design component-sizing criteria, and dam costing criteria.
- Details of additional dam sites that were identified on the Orange River along the common border.
- Details of a dam site that was identified on the Fish River.
- Details of pre-screening factors that were applied in making an initial elimination of dam sites.
- Details of the various pre-screening processes in which dam development options were eliminated from further consideration.
- A list of more promising dam sites that were considered in more detail.

- Comparison of the best dam development option with the previously-identified Vioolsdrif and Boegoeberg Dam sites.
- Explanation and results of economic analysis.

## 1.2 Methodology

The work relating to this task was carried out in the following manner:

- The Vaal Augmentation Planning Study's (VAPS) report on *Guidelines for the Preliminary Sizing, Costing and Engineering Economic Evaluation of Planning Options (DWAF, 1996)* was studied in order to review the dam design criteria, and update the costing models.
- The report on *Potential Dam Development and Hydro Power Options of the ORRS Study (DWAF, 1998a)* was studied and particular attention was paid to investigations and recommendations pertaining to dam development options.
- The reach of the Orange River, from the mouth of the river to 20° longitude, was inspected for possible dam sites which had not already been identified in the Orange River Development Project Replanning Study (ORRS).
- The reach of Fish River from the confluence with the Orange River to a point in the vicinity of Keetmanshoop was inspected for possible dam sites.
- A preliminary screening process was undertaken to identify all of the dam development options, which were considered to be flawed from an engineering, social or environmental viewpoint.
- Preliminary cost analyses were carried out to determine the most cost effective options from a capital cost and reservoir size viewpoint.
- A preliminary design was carried out on the most feasible dam development option identified in the pre-screening stage.

## 1.3 Previous Investigations

Previous investigations that are relevant to this study are:

- The Vaal Augmentation Planning Study: Guidelines for the preliminary sizing, costing and engineering economic evaluations of planning options.
- The Orange River Development Project Replanning Study: Potential Dam Development and Hydro Power Options.

These studies are discussed in more detail below.

**(a) Vaal Augmentation Planning Study: Guidelines for the Preliminary Sizing, Costing and Engineering Economic Evaluation of Planning Options**

During the execution of the VAPS, the Project Planning Directorate of the South African Department of Water Affairs and Forestry (DWAF) recognised that the standard methodology developed during the study for the sizing and costing of water resource project components and for the economic evaluation of water resource development options would be a valuable tool for subsequent planning exercises. It was accordingly decided to capture the guidelines in a single document, which would be made available to planning professionals, both within the Department and those consultants appointed by the Department, to undertake specific assignments.

The purpose of these guidelines was to provide a standard framework for first pass comparative costing and project economic evaluation of water resource development options. It was envisaged that as additional information was obtained on the options under investigation, that the models provided in the guidelines would be expanded and adjusted to reflect the actual circumstances more accurately. The guidelines were merely planning tools and were not suitable for the preparation of detailed designs, engineers' estimates or tender documentation.

Guidelines were given on the following aspects of dam development:

- Level of detail required for the different planning phases.
- Component signing criteria for embankment dams (earthfill with impervious core, rockfill with impervious core and rockfill with reinforced concrete upstream face), mass concrete dams, weirs, canals, syphons, pipelines, pumping stations, tunnels and pumped storage.
- Costing models for embankment dams, mass concrete dams, weirs, canals, syphons, pipelines, pumping stations, tunnels and multi-level intake structures.
- Social, environmental and administration costs, economic life, annual maintenance and operational costs.
- Method of measurement.
- Project economic evaluation models.

**(b) Orange River Development Project Replanning Study (ORRS): Potential Dam Development and Hydropower Options**

Various dam development options were initially evaluated as part of the Reconnaissance Phase of the ORRS. All development options considered in previous studies were included in the initial evaluation, together with new options identified by the Project Team.

Twenty-three development options were carried through to the Pre-feasibility Phase of the study, and were analysed in the chapter “Potential Dam Development and Hydropower Options”.

# 2. DEVELOPMENT OF DESIGN AND COST CRITERIA

## 2.1 Introduction

During the execution of the VAPS, the Project Planning Directorate of the South African DWAF recognised that the standard methodology developed during that study for the sizing and costing of water resource project components and for the economic evaluation of water resource development options would be a valuable tool for subsequent planning exercises. It was accordingly decided to capture these guidelines in a single document that could be made available to planning professionals, both within the Department and those consultants appointed by the Department, to undertake specific assignments (DWAF, 1996).

In the Terms of Reference (ToR) for the LORMS project, it was stated that these guidelines could form the basis for the preliminary designs and initial cost analyses. Therefore, for the purposes of the LORMS, the design criteria utilised in the VAPS study were reviewed and modified where deemed necessary, and the cost models updated by utilising contract prices for the Maguga, Mohale, Inyaka and Bivane (Paris) Dams, as well as the Matsoku Weir. Due to the specific nature of this study, namely the development of dam options for the Lower Orange River (LOR), only the design criteria and cost models for dams were reviewed.

The reviewed and modified cost criteria have been compiled into a separate document, attached hereto as **Appendix A**.

## 2.2 Changes made to the Component Sizing Criteria

The component sizing criteria utilised in the VAPS were reviewed and modified where deemed necessary. In particular, the sections on flood determination for the various dam types were rewritten due to inconsistencies in the terminology and presentation in the VAPS guidelines. Anomalies between the sections on typical dimensions and the figures were corrected. The sections on foundation grouting were rewritten to be consistent between the various dam types. References to the sizing of outlet works were consolidated under the section on intake and outlet works. The references to typical costs for mechanical items were moved from the design guidelines to Section 5.9.

The sizing guidelines adopted for the walls of embankment dams and mass concrete dams are shown in **Table 2.1** and **Table 2.2**.

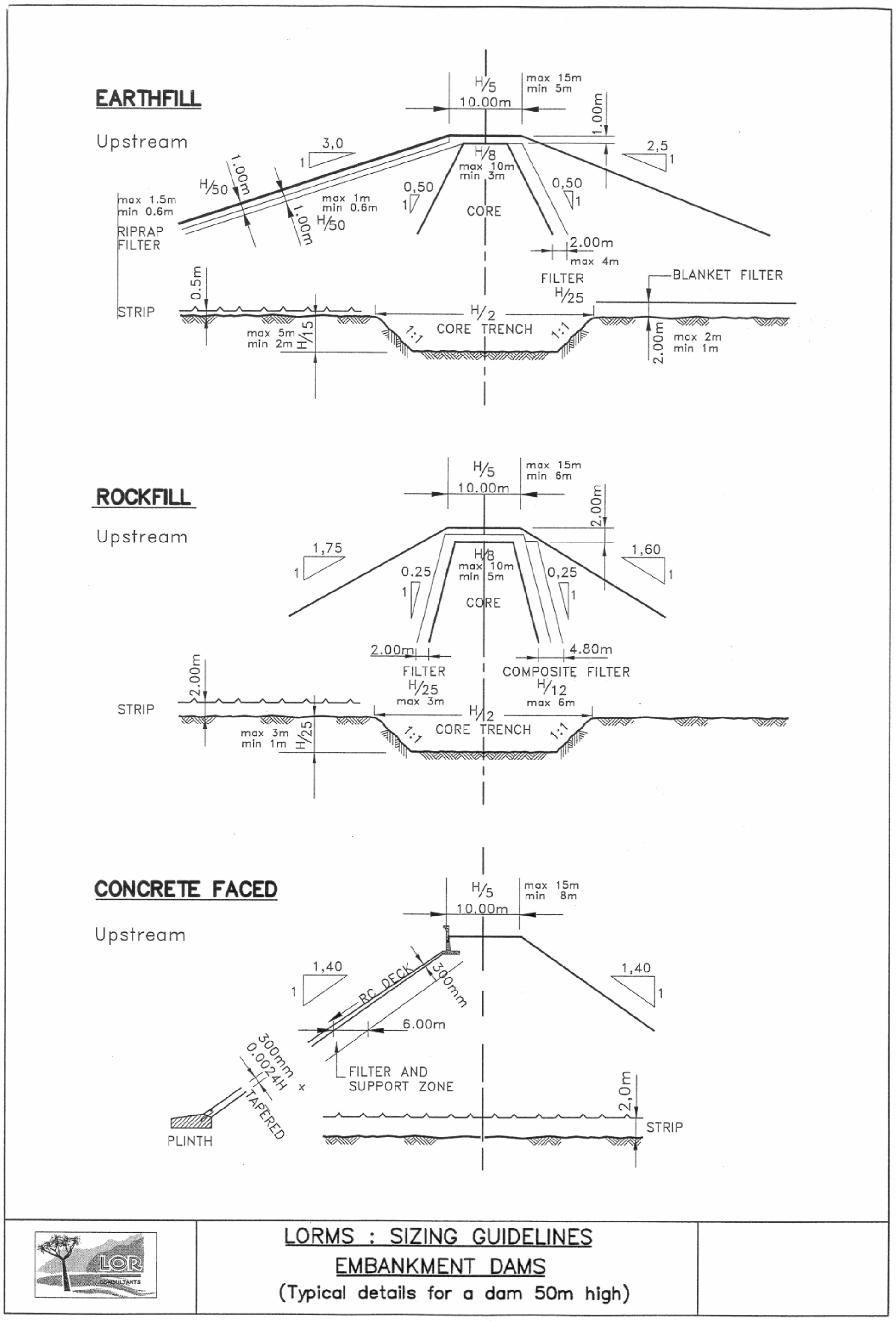


**Table 2.1: Embankment Dams: Sizing Guidelines**

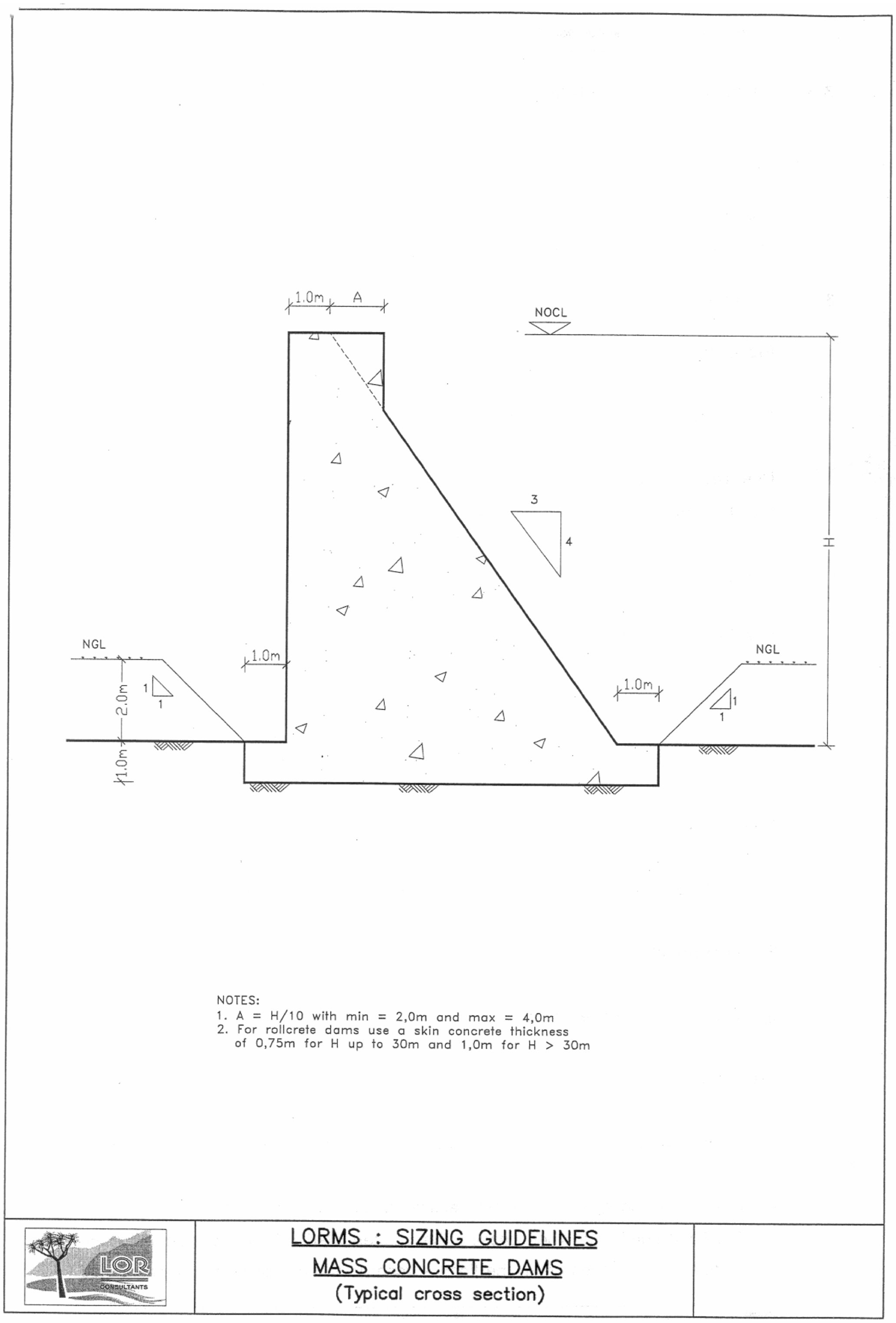


**Table 2.2: Mass Concrete Dams: Sizing Guidelines**

## 2.3 Changes made to the Costing Models

### *2.3.1 Introduction*

Simple spreadsheet models, each comprising a bill of rates, were prepared for first pass pricing of the following dam types:

- Earthfill embankment dams;
- Rockfill embankment dams;
- Mass concrete dams; and
- Rollcrete dams.

The cost models were standardised, with one page measuring direct cost items, and one page for Preliminary and General Items and items for design, supervision and contingencies.

### *2.3.2 Review of Costing*

#### 2.3.2.1 Sources of Information

The following sources of information were used. The reasons for using the source, as well as the pitfalls with regard to the unit prices are also given:

**Maguga Dam**

Maguga Dam is a 115 m high clay core rockfill dam on the Komati River in Swaziland. It was completed in February 2002.

The latest payment certificate (No. 44) was used, being a fair representation of the final value of the project. As the tender prices were very keen at the time, the unit rates are considered to be low. The value of any variations or claims particular to a work section was therefore added to the total value of that section to arrive at a more realistic cost.

**Mohale Dam**

Mohale Dam is a 145 m high concrete-faced rockfill dam on the Sengunyane River in Lesotho. It was completed in March 2002.

The original priced bill of quantities of the awarded contract was used. There were very few claims or variations on this contract. The contractor was also already "on site", which would have had a significant influence on some of the rates, especially the rate for placing the rockfill.

**Injaka Dam**

The Injaka Dam is a 53 m high earthfill dam on the Marite River in Mpumalanga. It was completed in 2001.

The latest payment certificate was used as there are major variations and claims on the original bill of quantities (R67 million out of R216 million, which have a substantial influence on the unit rates). It is also interesting to note that, although this dam seems to have a major earthfill embankment, the cost of the earthfill section is relatively small in relation to the total cost, being only 14%. Should some of the cost in the "Miscellaneous" (20%) or "Preliminary and General" (46%) sections be allocated to the unit rates of the earthfill, these rates would be more realistic.

**Matsoku Weir**

The Matsoku Weir is a 19 m high mass gravity concrete structure on the Matsoku River in Lesotho. It was completed in October 2002.

The latest payment certificate (No. 54) was used, being a fair representation of the final value of the project. As the tender prices were very keen at the time, the unit rates are considered to be on the low side. The contract also included the Matsoku Tunnel to Katse Dam and is therefore not considered to be completely representative of a dam project. In particular the "P & G" section comprised 176% of the unit rate sections.

**Bivane (Paris) Dam**

The Bivane (Paris) Dam is a 68 m high concrete arch dam on the Bivane River in Kwazulu-Natal. It was completed in the year 2000.

The third-lowest tender was used as the awarded tender does not provide realistic values. The contractor and the owners are still busy with litigation more than 2 years after completion of the contract. This tender (the 3rd lowest) was also the one recommended to the owners of the dam. With regard to the unit prices from this document, the following was kept in mind:

- The site is perfectly suited for an arch dam.
- Prices for the foundation excavation and formwork were higher than for gravity dams due to the difficult access and the general complexities involved with an arch dam.

#### 2.3.2.2 Methodology

The following methodology was applied*:*

- All items in each document were classified according to the items used in the VAPS document. Those items that did not fall under any specific item were classified under “Miscellaneous”.
- A weighted average was then determined for the unit rates of each item.
- Finally, using the unit rates determined and the percentages for items such as Landscaping, Miscellaneous and Preliminary and General, the total cost of a selection of the projects was tested using the applicable cost model compared to the actual cost to make sure that all costs were included in the unit rates and the percentages.

#### 2.3.2.3 Updating of VAPS Rates

The unit rates in the VAPS cost models were escalated to April 2004 by using high plant component indices for the embankment dams and high material indices for the concrete dams. These rates were then compared to the rates developed above and appropriate values were selected for inclusion in the LORMS cost models.

# 3. IDENTIFICATION OF DAM SITES

## 3.1 Purpose of Sub-Task

The purpose of this sub-task is:

- To mark up all the relevant options identified in the ORRS on the 1:50 000 topographical maps (the study area of the ORRS that was considered to be of relevance to the LORMS, was taken as the area downstream of Vanderkloof Dam).
- To identify any new options to the west of the 20° longitude along the common border between South Africa and Namibia (i.e., in addition to those already identified in the ORRS).
- To identify a potential dam site on the Fish River, the reservoir characteristics of which were required for input into the hydrological model of the LOR.

## 3.2 Methodology

### *3.2.1 Options Upstream of the Common Border*

Details on the potential development options identified in the ORRS were obtained from the chapter "Potential Dam Development and Hydro Power Options" of the ORRS Study.

### *3.2.2 Options along the Common Border*

The initial identification of potential dam sites along the common border was done with a view to identify all options from a topographical perspective only. Other factors were evaluated during the pre-screening phase.

The following factors were considered in the identification of potential dam sites along the common border:

- The width of the valley.
- The suitability of the site for the construction of an auxiliary by-wash or off-channel spillway (a dam on the LOR would have to be able to pass floods in excess of 25 000 $m^3$/s).

- The height to which a dam could be constructed before water starts spilling over into adjacent areas, thereby by-passing the dam.

The following factors were not taken into account at this stage, but were considered in more detail in the next investigation stage as is reported in **Section 5**:

(1) Potential storage capacity.
(2) Whether a smaller dam (i.e., a re-regulating dam) or larger dam (i.e., to increase the yield of the system) was required.
(3) Proximity to other identified sites.
(4) All impacts, such as:
  - Inundation of land, whether it was developed or not;
  - Inundation of road, rail and other infrastructure;
  - Inundation of towns and villages;
  - Inundation of sites of historical or archaeological interest;
  - etc.

### *3.2.3 Options on the Fish River*

The following factors were considered in the identification of a potential dam site on the Fish River:

- To maximise the value of the dam, it had to be as close to the confluence with the Orange River as possible in order to utilise the available run-off.
- As the initial purpose of identifying a dam site on the Fish River was to determine the reservoir characteristics for input into the hydrological model of the LOR, it was not necessary to determine the absolute optimum site.
- It was assumed that a dam within the Ai-Ais Nature Reserve would not be acceptable and no potential dam sites between the northern border of the Reserve and the confluence of the Orange River were investigated.

## 3.3 Potential Dam Sites Identified

### *3.3.1 Options Upstream of the Common Border*

During the Reconnaissance Phase of the ORRS, twenty-three possible development options were identified along the Orange River. The eight options upstream of the common border are listed in **Table 3.1** below and their positions shown in **Appendices C10** to **C12**.

**Table 3.1: Development Options Identified in the ORRS Upstream of the Common Border within the LORMS Study Area**

| Development Option | Location |
|---|---|
| New Boegoeberg Dam | ~ 1 km downstream of existing Boegoeberg Dam |
| Hospital Dam | ~ 20 km upstream of Prieska |
| Lanyonvale Dam | ~ 60 km downstream of Douglas |
| Torquay Dam | ~ 47 km downstream of Hopetown and ~ 35 km upstream of Vaal/Orange confluence |
| Hereford Weir | ~ 35 km downstream of Hopetown |
| Eskdale Weir | ~ 15 km downstream of Hopetown |
| Elandsdraai Dam | ~ 15 km upstream of Hopetown |
| Havenga Bridge Dam | ~ 15 km downstream of Vanderkloof Dam |

### *3.3.2 Options along the Common Border*

#### (a) Dam Sites Identified

All the potential dam sites along the common border that were identified in this study, as well as those identified in the ORRS, are listed in **Table 3.2**, and their positions indicated on the 1:250 000 maps in **Appendices C2** to **C7**.

**Table 3.2: Development Options Identified along the Common Border**

| Name of Dam Site | Appendix | Approximate Chainage [1] (km) | Comment |
|---|---|---|---|
| Kabies | C2 | 148 | Identified in ORRS |
| Grootpens A | C3 | 173 | |
| Grootpens B | C3 | 177 | |
| Aussenkehr | C3 | 223 | Identified in ORRS |
| Vioolsdrif A | C4 | 303 | Identified in ORRS |
| Vioolsdrif B | C4 | 318 | Identified in ORRS |
| Vioolsdrif C | C4 | 322 | Identified in ORRS |
| Vioolsdrif D | C4 | 327 | |
| Kambreek | C6 | 433 | Identified in ORRS |
| Coboop A | C6 | 465 | |
| Coboop B | C6 | 475 | |
| Coboop C | C6 | 479 | |
| Beenbreek | C7 | 512 | |
| Yas | C7 | 542 | |
| Komsberg | C7 | 580 | |

Note

1. The chainage is the approximate distance measured along the Orange River, starting at the mouth of the river.

### (b) Basis of Identification as a Potential Dam Site

(1) Sites between Oranjemund and the confluence of the Fish River:

- The Kabies site is situated downstream of the confluence of the Fish and Orange Rivers, and was identified in the ORRS. Due to the wide valley at the site, the site has poor characteristics compared to the other sites identified on the Orange River, but is the best site downstream of the confluence.

(2) Sites between the confluence of the Fish River and Vioolsdrif / Noordoewer:

- The Grootpens A and B sites were selected on the basis of the river valleys being relatively narrow at the sites.
- The Aussenkehr site was identified in the ORRS.

(3) Sites between Vioolsdrif / Noordoewer and Onseepkans:

- The Vioolsdrif A, B and C sites were identified in the ORRS.
- The Vioolsdrif D site was identified in this (the LORMS) Study as the site appears to be narrower than the A, B or C sites.
- The Kambreek site was identified in the ORRS.
- The Coboop A, B and C sites were identified because of the relatively narrow widths of the valleys at the sites.

(4) Sites between Onseepkans and 20$^o$ longitude:

- Twenty-four dam sites were investigated over the reach between the 20$^o$ longitude and Onseepkans at Beenbreek, Naros, Warmbad, Ondermatje, Yas, Stolzenfels, Skuitdrif, Narries and Komsberg.
- The Komsberg Dam site was selected as a potential site as it has a relatively narrow valley (e.g., narrower than that of the Vioolsdrif A site).
- The topography of the Yas and Beenbreek sites offers the possibility of constructing by-wash or off-channel spillways (depending on the required elevation for the spillway).
- The other sites were all eliminated due to larger cross-sectional areas than the above sites.

### *3.3.3 Options on the Fish River*

The Fish River runs in a relatively narrow gorge over much of the reach between Keetmanshoop and the confluence with the Orange River. A site was selected at Koubis, immediately upstream of the Ai-Ais Nature Reserve, as being representative of typical sites in the area to provide reservoir characteristics for input into the hydrological model of the LOR. If the initial runs of the hydrological model indicated that a dam on the Fish River could be attractive in the regional context, further investigations to optimise the selection of the site would have been carried out.

The location of the Koubis Dam site is shown on the 1:500 000 map in **Appendix C13**.

# 4. ENVIRONMENTAL CONSIDERATIONS AND EXISTING INFRASTRUCTURE

## 4.1 Introduction

Before Task 4.1b (Pre-screening of Development Options) could be undertaken, background data had to be obtained on the environmental considerations associated with, as well as the existing infrastructure that could be affected by the proposed options. The following pre-screening factors were investigated and are reported on in this section:

- Reaches of ecological importance and sensitivity.
- Areas of archaeological and historical interest.
- Presently cultivated land or land that could potentially be cultivated in future, and which will be inundated due to dam development.
- Land over which various mining and prospecting licenses had been issued, and for which the licensees would have to be compensated for areas that would be inundated.
- Roads and bridges across the river that would possibly have to be re-routed.
- Towns and villages that would be inundated.
- National Parks.
- Powerlines across the river that would possibly have to be re-routed.

## 4.2 Ecological Importance and Sensitivity of the Lower Orange River

In the execution of Task 5 (Environmental and Social Issues), a report was prepared by the Consultant titled "The Ecological Importance and Sensitivity of the Lower Orange River Downstream of 20° Longitude to the Orange-Fish River Confluence". Sections of the report, which are relevant to the Dam Development Options task, are summarised in the paragraphs below. For more detailed information, the above report should be consulted.

### *4.2.1 River Flow*

The median monthly flows in the previously termed Middle Orange River, with Boegoeberg Dam as point of reference, were calculated, using data from 1914 to 1989. The Orange River System's natural flow patterns showed an 82% summer (October to May) / 18% winter (May to October) distribution.

Since the Vanderkloof Dam became operational in 1977, the natural flow regime of the Middle Orange River has become greatly dampened, changing to a 59% summer / 41% winter flow distribution. Together with the Gariep Dam, the Vanderkloof Dam also has a dampening effect on floods in the LOR as these two impoundments are capable of totally or partially absorbing the minor to medium floods required for ecological/environmental maintenance.

### *4.2.2 Issues of Concern in respect of Dam Construction in the Orange River Reach from 20° Longitude to the Orange-Fish River Confluence*

#### 4.2.2.1 Physico-chemical Effects of an Impoundment on a River

Medium to large impoundments normally display thermal stratification during summer, e.g., an epilimnion (warm, productive, upper water layer), a thermocline (transitional layer) and a hypolimnion (cold, mainly unproductive bottom water layer). During winter, thermal stratification is much less pronounced, to completely absent in such an impoundment. The depth and productivity of the epilimnion depends to a large extent on the transparency/turbidity of the water in the impoundment. Being the impoundment's productive layer, a lot of physico-chemical (temperature, oxygen content, pH, etc.) and biological (plankton production) modifications to the incoming river water occur in the impoundment's epilimnion. This can result in major differences in the epilimnetic layer's physico-chemical and biological character in comparison with the downstream river water. This situation is aggravated by mineral accumulation in the impoundment, which, in combination with the extreme evaporation rates along the study area route, can lead to serious deterioration in water quality (impoundment and downstream river) and even to eutrophication. On the other hand, the impoundment's hypolimnetic water is usually much colder, and also poorer in oxygen content than the downstream river water. Water releases, whether epi- or hypolimnetic, from such an impoundment to the downstream river during summer can therefore send a host of physico-chemical and biological shocks through the river stretch, which will negatively impact on the downstream biota.

Waterfalls and rapids are extremely important in replenishing the oxygen lost from the riverine environment by water abstraction and the high temperatures characteristic of the entire study area. This should definitely receive serious attention during dam site selection, as inundation of such river phenomena will have detrimental effects on the riverine biota.

Dam construction and river regulation usually lead to increases in riparian agricultural activities, especially irrigation (catchment utilisation). This, in turn, will inevitably lead to agricultural pollution resulting in changes to the river oxygen content, pH, turbidity and conductivity.

Riverbed degradation resulting from suspended solid precipitation caused by the combination of low flows (river regulation), high evaporation rates and high mineral content (agricultural and other pollution) leads to aquatic habitat degradation, which could be detrimental to the survival of certain indigenous, including endemic, organisms, while being promotive to the unwanted establishment of other indigenous, as well as alien organisms.

4.2.2.2 Effects of an Impoundment on the Riverine Biota

- **Vegetation**

  The technically pristine inland deltas and shoreline and island vegetation along the inaccessible floodplain stretches of the study area's main river channel will be threatened by dam construction as these stretches' mountainous character provides ideal dam sites. This will result in their being inundated. These river stretches should rather be considered for conservation because of their value as vegetation benchmarks and habitat for stream preferring aquatic organisms. On the other hand, lower, stabilised water flow volumes will negatively affect natural shoreline and island vegetation communities downstream of a major dam. This, in turn, will result in riverbank destabilisation.

  Increasing river regulation and catchment utilisation will result in increases in filamentous Phycophytes and blue-green alga (algal blooms), and will also promote habitat changes suitable for the encroachment and colonisation of plant species such as the American floating water fern, water weeds and the river reed. 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, of which individuals have already been observed as far downstream as the Orange River mouth. It will also create habitat advantageous to certain fish species (indigenous and alien), while negatively affecting others (certain endemic and indigenous ones).

- **Freshwater invertebrates**

  It can be expected that further river regulation will enhance habitat possibilities for economically important invertebrates such as Blackflies, the snail intermediate hosts of Bilharzia and Fluke spp., mosquito's, etc. Certain free-living aquatic invertebrates might also gradually make their appearance. Together with increasing parasite infestations amongst the fish populations, they can serve as indicators of water quality deterioration. It will therefore be absolutely necessary to involve aquatic invertebrate specialists in possible further river regulation investigations.

- **Freshwater fish species**

  The key freshwater fish species of major concern in respect of dam construction in the LOR stretch between 20º longitude and the Orange-Fish confluence are listed in **Table 4.1**.

**Table 4.1: Key Freshwater Fish Species Expected to be affected by Dam Construction in the LOR Stretch between 20º Longitude and the Orange-Fish Confluence**

| Common Name | Status | | | |
|---|---|---|---|---|
| | **Endemic** | **Indigenous** | **Vulnerable** | **Red Data** |
| Namaqua Barb | X | | | X |
| Largemouth Yellowfish | X | | | X |
| Rock Catfish | X | | | X |
| Smallmouth Yellowfish | X | | | |
| Orange River Mudfish | X | | | |
| Threespot Barb | | X | X | |
| Straightfin Barb | | X | X | |

Five of the six endemic Orange River System (ORS) fish species occur in this river section, of which one, the Namaqua Barb, is unique to the Orange River section between Aughrabies Falls and the Orange River Mouth. Three of the five endemic species, namely the Namaqua Barb, Largemouth Yellowfish and Rock Catfish are Red Data listed. Although the other two endemic species, namely the Smallmouth Yellowfish and Orange River Mudfish, are fairly abundant and thus appear not to be threatened, they remain of concern because of their endemic status.

For instance, in the Orange River stretch between Vanderkloof Dam and the Orange-Vaal confluence, it appears that the Orange River Mudfish populations are approaching "bottle-neck" situations as a result of the extreme effects of river regulation in this river section. On the other hand, in the over-extended Lower Vaal River (Vaalharts Weir to Orange-Vaal Confluence) the Smallmouth Yellowfish populations also appear to be approaching "bottleneck" situations.

Although the Threespot Barb and the Straightfin Barb are not endemic species, their relatively low numbers thus far, recorded from the Orange River section between Augrabies Falls and the Orange River Mouth, make them vulnerable to changes in the main river channel. Their indigenous status in the river section makes it important biotic components of the river section's total ecology. As in the case of endemic species, any threat to an indigenous species is indicative of negative impacts on the ecosystem. For instance, siltation of rapids in the Lower Vaal River (Vaalharts Weir to Orange-Vaal Confluence) resulted in the Threespot Barb nearing extinction in this river section.

#### 4.2.2.3 Impacts of Dams/Large Weirs on the Aquatic Biota of Rivers

- Dams/large weirs form major migration barriers resulting in genetic compartmentalisation and inbreeding of aquatic populations. This enhances the manifestation of poor genetic characteristics, weakening populations and sometimes leading to extinction. It is therefore extremely important to consider fishways as integral parts of dam/weir construction in river courses in order to maintain genetic diversity within aquatic populations. It must be kept in mind that there is more in a fishway than only providing for aquatic organisms to cross the artificial barrier.

- Because thermal stratification is rather characteristic of large dams, structures for downstream water releases should be designed to allow for mixing in order to minimise physico-chemical shocks in the downstream river section.

- The height of a dam wall determines the length of the resulting inundated river stretch, as well as the size of the impoundment's surface area, which includes peripheral land and tributary stretches to be submerged. Because the ORS is poor in indigenous freshwater fish species diversity, and 12 out of the 15 indigenous ORS freshwater fish species, including one unique Red Data listed endemic Namaqua Barb, one unique indigenous (River Sardine), two endemic

Red Data listed (Largemouth Yellowfish and Rock Catfish) and two vulnerable indigenous (Threespot Barb and Straightfin Barb) fish species occur in the river stretch between Augrabies Falls and the Orange River Mouth, it is important that this diversity is maintained. It is therefore important the fish species' habitat, and especially instream habitat, requirements are considered when dam sites are selected. From an environmental impact and management point of view, two or more properly sited smaller dams/weirs are preferred to one large dam.

4.2.2.4 The Ecological Importance and Sensitivity of Different River Reaches in the Orange River Reach from 20º Longitude to the Orange-Fish Confluence

The co-ordinates of river reaches in the Orange River stretch 20º longitude to the Orange-Fish confluence considered to be of ecological importance are presented in **Table 4.2** and their locations indicated in **Appendices C2 to C7**. These reaches were identified by using 1:50 000 topographical maps.

**Table 4.2: River Reaches in the Orange River Stretch 20º Longitude to the Orange-Fish Confluence considered to be of Ecological Importance**

| River Reach | | | Reason for Importance | Dams possibly affected by |
|---|---|---|---|---|
| No. | From | To | | |
| 1 | 28º 50' 15" S 19º15' 00" E | 28º 39' 00" S 19º29' 40" E | Inland delta | Kambreek<br>Coboop A, B & C<br>Beenbreek |
| 2 | 28º 53' 30" S 18º30' 30" E | 28º 57' 20" S 19º04' 20" E | Inland delta | Vioolsdrif |
| 3 | 28º 42' 20" S 17º28' 30" E | 28º 27' 30" S 17º20' 20" E | Unique riverbed | Grootpens A & B<br>Aussenkehr |
| 4 | 28º 19' 30" S 17º22' 30" E | 28º 06' 00" S 17º10' 40" E | Unique riverbed | Kabis |

In **Table 4.2** it will be noted that river reaches numbers 3 and 4 both indicate "unique riverbed" as reason for ecological importance. The reason is that a unique riverbed section was observed, consisting of a solid rock bank lining a narrow channel through which the river runs, during an aerial survey. Unfortunately, it was not recorded exactly where this phenomenon was observed – it was, however, observed in the northerly flowing river stretch downstream of Vioolsdrif. Only two of these unique riverbed stretches occur in the entire Orange River – the other one being at Hopetown. It is suggested that the four river reaches indicated in **Table 4.2** and in the annexures are further investigated for their ecological importance by an in-depth aerial photograph study and/or an aerial survey. Aerial photographs of typical sections of a 'unique riverbed' and of an 'inland delta' are indicated in **Appendix C8**.

## 4.3 Report on the Heritage Sensitivity of the South African Side of the Orange River Downstream of 20$^o$ Longitude

### *4.3.1 Introduction*

As part of Task 5, the Archaeology Contracts Office of the University of Cape Town was appointed by the Consultant to conduct a literature and information review to establish the archaeological sensitivity of the LOR from immediately west of Augrabies National Park to the confluence of the Orange and Fish Rivers (South African territory only). The purpose of the study was to provide input into screening of potential options for a dam.

### *4.3.2 Method*

No fieldwork was conducted during this study, and the findings described in the report were based on reliable anecdotal observations by other archaeologists, published documents, dissertations and unpublished reports and papers.

### *4.3.3 Restrictions*

Despite fairly exhaustive enquiries, information with respect to the study area was virtually non-existent. Virtually every area that has been subject to any research lies outside the study area. There are no site records and no one has completed any formal documented surveys. The information available is limited to a few casual observations on sites that have not been mapped or afforded reliable co-ordinates. The archaeology of the study area is to all intents and purposes, unexplored and unknown.

### *4.3.4 Available Information*

#### 4.3.4.1 Area between the Mouth of the Orange River and the Richtersveld

All reliable observations are restricted to the area between the mouth of the Orange to the Richtersveld West, including the confluence of the Fish and Orange Rivers.

Between 1996 and 2002, surveys were conducted in diamond mining concession areas in the Richtersveld. This resulted in some 40 km of a 1 km wide strip of the southern bank of the river (between Sendelings Drift and Baken) being surveyed in detail, revealing the presence of Early, Middle and Late Stone Age archaeological material. The following kinds of sites were located:

- **Early Stone Age** sites, found in and on river gravel terraces and even noted a considerable distance from the river on the Namibian side within the *Sperrgebiet*.

- Scattered **Middle Stone Age** material, found on river terraces, on ridges overlooking the river as well as on the higher slopes of hills.

- **Late Stone Age** sites, mostly confined to riverine silt bodies. A number of herder sites were located, some of which have been radiocarbon dated and sampled. Also present are Mid-Late Holocene sites, one of which contain a microlihic industry and have been radio-carbon dated to circa 3000 BC.

- **Rock Engravings**, prolific within the river valley and tributaries. Most of these are etched onto blue dolomite. The designs tend to be abstract, yet consistent. Human and animal figure are rare but present. The age of the engravings is unknown. Some appear to be fairly fresh while others are so worn and patinated that they must be of considerable age – possibly some thousands of years. The meanings of the enigmatic designs remain unknown and their significance is unclear.

- **Historic Sites**, including the foundations of the historic mission church at Sendelings Drift, places on the river where early copper mines in the Richterveld shipped copper ore onto river barges for transport down river. The stone burial mounds of Nama herders were noted throughout the study area.

- **Ethno-archaeological Sites**, consisting of the remains of herder encampments that are not necessarily protected by heritage legislation, but are important as they are the last physical remnants of a traditional lifestyle that is thousands of years old and rapidly changing in the 21$^{st}$ century. These sites are of interest to anthropologists, ethno-archaeologists and architects who have mapped and documented the layout of these encampments in attempts to understand changes and traditional values within Nama society.

#### 4.3.4.2 Area Immediately West of Augrabies Falls

The area immediately west of the Augrabies Falls has been subject to archaeological research by means of informal surveys, which have been conducted within the National Park and on river-bordering farms in the Kakamas area.

Information obtained from the SAHRA library indicates that there are various sites of historical and archaeological interest at the places indicated in **Table 4.3**.

**Table 4.3: South African Side of the Orange River: Sites of Historical and Archaeological Interest**

| Site | Reason for Interest |
|---|---|
| Skuitdrif | Historic river crossing<br>German military outpost built in 1901<br>Ruins and graves |
| Pella | Very important regional historic site<br>Museum<br>Tourist attraction<br>Catholic mission church, built in 1878<br>Date plantations |
| Onseepkans | Declared National Monument<br>Historic bridge |
| Goodhouse | Graves and church<br>Historic buildings |
| Daberas | Ruins |
| Pofadder | Historic mission station & a declared monument |
| Riemvasmaak | Identified archaeological sites |

### *4.3.5 An Estimation of Sensitivity*

Although very little is known about the archaeology of the study area, it is bracketed by zones where some archaeological research has been conducted. The Richtersveld to the west is known to be very archaeologically sensitive in terms of the unique herder sites that have been identified along its banks. This is the only area in South Africa where these sites have been identified. Similar sites have been identified along the Middle Orange River to the east so it would seam reasonable to assume that the chances of such occurring within the study area is very likely. Similarly, a variety of historical, para-historical and pre-colonial sites, ranging from Early to Late Stone Age, can be expected.

The predicted sensitivity of the different landscape with the study area is as follows:

- **Immediate river bank, silt deposits**
  Buried and exposed pottery and fish bone rich sites of ancestors of the Nama, burial cairns of Nama. Experience has shown that highly sensitive areas are often located at the confluence of tributaries leading into the Orange. Older San and other Holocene sites have also been documented on the silt flats and in any small rock shelters or overhangs close to the river.

- **Flat rocky outcrops, especially dolerite**
  It is almost guaranteed that there will be rock engravings on such outcrops.

- **Old river terraces, ridges**
  These may hold general scatters of archaeological material, especially Early and Middle Stone age.

- **Tributaries and steep sided valleys**
  Such areas are likely to be archaeologically sensitive, especially if they contain shelters and overhangs, as well as pools or fountains of permanent water.

- **Historic and ethnographic sites**
  There are likely to be encampments abandoned by Nama herders along the banks of the river. Furthermore, within the maximum flood level, there will be historic buildings (early farms, missions), graveyards, possible places of conflict (Anglo-Boer war and Korana uprising).

#### *4.3.6 Conclusions*

The following conclusions were made in the report:

- Extrapolating what is known from localities to the east and west of the study area, the report stated that it could reasonably be predicted that any potential dam site within the study area will have heritage impacts.

- The Richtersveld is archaeologically rich and inundation of the river valley will have an impact in the immediate vicinity of the river.

- The report stated that it is clear that a preliminary field assessment is going to be necessary before any idea of the kinds of impacts that may be involved can be gained. As a first step, a physical inspection of the area and a strategy to "sample" portions of land representative of topography, geology and at differing differences from the river was required to get an idea of the range of sites, their relative density from place to place and the degree of loss that a large development such as this will cause to the National Estate.

- Some detailed archival research may also be necessary to identify places of conflict, as well as help establish the significance of any sites found.

## 4.4 Report on the Heritage Sensitivity of the Namibian Side of the Orange River Downstream of 20$^o$ Longitude

In a report prepared for Task 5, titled *"A Preliminary Archaeological Assessment of the Lower Orange River", J Kinahan (2003)*, the status of archaeological remains and historical interest of the northern bank of the Orange River along the common border were identified. The report states that survey data available from the mouth of the Boom River, the mouth of the Haib River and the vicinity of Stolzenfels provides more detailed indications of the type of archaeological remains found in the LOR valley. The positions of the three surveyed localities in the LOR valley are indicated in **Appendices C1**, **C2, C4** and **C7**.

Based on present knowledge, the archaeological characteristics of the LOR can be summarised as follows:

- The full (mid-) Pleistocene (Middle Stone Age) to Holocene and recent historical sequences is represented.
- Archaeological site distributions can be predicted on the basis of landscape associations.
- Major tributary stream confluences are important archaeological localities, especially in the vicinity of springs and seepages.
- The present banks of the Orange River are relatively unimportant localities.
- River crossings and access routes are historically important features.
- Recent grave sites tend to be located on the banks of the Orange River.

The report states that an archaeological assessment of the LOR will provide more detailed knowledge of an interesting, but poorly known area. It is not anticipated that the survey would yield major archaeological finds that might present a "fatal flaw" in any proposed development. On the contrary, an archaeological assessment of the area is likely to record a large number of small sites indicating intermittent settlement of the Orange River valley throughout the archaeological record. The most important findings expected from the area would include:

- *In situ* Pleistocene stone artefacts in spring tufas and overbank flood deposits.
- Well-defined associations between later Pleistocene sites and resource concentrations.
- Well-defined patterns of nomadic pastoralist stockpost location on the Orange River and its major tributaries.
- An improved knowledge of rock engravings site distribution in this area.
- Detailed knowledge of the archaeological and historical use of river crossings as trade routes.
- The location of recent (historical) and archaeological graves that may have to be moved in the event of dam construction.

## 4.5 Cultivated Land

During the course of the investigation into water demand and management, presently cultivated areas along the common border were recorded, and potentially irrigable areas were identified along both the South African and Namibian sides of the border. Refer to the report on Water Demand and Management in Task 3 for more information on the identification and classification of cultivated land.

Much of these areas lies along the banks of the river, and may therefore be inundated by water impounded by a dam that is constructed on the river. Refer to **Appendices C1** to **C7** for the locations of the cultivated areas.

## 4.6 Mining and Prospecting Licenses

### *4.6.1 South Africa*

According to the publication *"The Mineral Resources of South Africa" (Council for Geoscience, 1998)*, several mining activities had been or is still taking place along the LOR.

In the section of the river downstream of Vioolsdrif, diamondiferous gravels have been prospected or exploited in at least 40 deposits, 21 of which occur on the South African bank of the river. Numerous pegmatites occur in the area on the farms Steinkopf 22 and Vioolsdrif 226. Some of these pegmatites are mined sporadically by means of hand cobbing. Fluorspar has been found in the pegmatite field developed in the vicinity of Onseepkans.

Tungsten deposits occur in the narrow stretch of highly dissected terrain flanking the Orange River from near Vioolsdrif to Pella. Although tungsten was first mined on an organised basis in 1934 at Groendoorn 23 km south of Vioolsdrif, and there have been sporadic short-lived tungsten operations in recent years, the main period of mining activity was during World War II. A deposit of scheelite was recovered on the farm Coboop 89 some 20 km south of Onseepkans. Tungsten was also mined on the farm Daberas 8, some 7 km west of the 20° longitude, between 1938 and 1943.

According to the Department of Mines and Energy in Springbok, no further prospecting licenses have been issued on the South African side of the common border, but this should be investigated in more detail for the preferred dam site (see **Appendix C14**).

### *4.6.2 Namibia*

The areas over which mining and prospecting licenses of one kind or another have been issued are indicated in **Appendices C1** to **C7**. The license numbers are given in **Table 4.4**. As can be seen from the maps in the appendices, licenses have been issued over just about the whole reach of the river along the common border. Officials of the Namibia Ministry of Mines and Energy indicated that the Ministry does not have the authority to cancel or prevent the renewal of licenses that have been issued, unless it can be proven that the licensee is not complying with the conditions of the license (e.g., not actively mining or prospecting on the land for which the license has been issued). Mining and prospecting licenses could therefore be considered in the same category as water and property rights, that is the owners and licenses holders have to be financially compensated if they have to give up their rights.

**Table 4.4: Mining and Prospecting Licenses Issued**

| License No. | | Type |
|---|---|---|
| 2557 | 3049 | Exclusive prospecting license |
| 2963 | 3050 | |
| 2744 | 2101 | |
| 2610 | 2656 | |
| 2628 | 2337 | |
| 2844 | 2228 | |
| 2278 | | Mineral deposit retention license |
| 2857 | 3034 | Exclusive prospecting license |
| 2989 | 3027 | |
| 2751 | 2872 | |
| 3046 | 2912 | |

Note:

This table reflects the status on 7 October 2002 of licenses issued by the Ministry of Mines and Energy (Namibia)

## 4.7 Roads and Bridges

A number of bridges across the Orange River link Namibia and South Africa. The extent to which these bridges and their approaches will be inundated by any dams constructed on the river will depend on the full supply levels of the dams. The bridges are listed in **Table 4.5** below.

**Table 4.5: Bridges across Orange River along the Common Border**

| Location | | Dams that may result in the bridges being inundated |
|---|---|---|
| Name of bridge | Distance from river mouth (km) | |
| Oranjemund / Alexander Bay | 10 | (none) |
| Vioolsdrif / Noordoewer | 275 | (none) |
| Onseepkans | 493 | Kambreek<br>Coboop A, B & C |

## 4.8 Towns and Villages

The towns and villages which are situated close to the banks of the Orange River and may therefore be partly or wholly inundated by water impounded by any new dams constructed along the common border are listed in **Table 4.6** below. Refer to **Appendices C1** to **C7** for the locations of these towns and villages.

**Table 4.6: Locations of Towns and Villages**

| Location of Town or Village | | Dams that may Inundate Parts of Towns & Villages |
|---|---|---|
| Name of Town or Village | Distance from River Mouth (km) | |
| Vioolsdrif | 275 | (none) |
| Noordoewer | 275 | (none) |
| Goodhouse | 354 | Vioolsdrif<br>Kambreek |
| Onseepkans | 493 | Kambreek<br>Coboop A, B & C |

## 4.9 National Parks

On the Orange River, the two national parks listed in **Table 4.7** will be affected by dam construction to a degree.

**Table 4.7: Locations of National Parks that may be affected by Dam Construction along the Common Border**

| Location of Park | | Dams that may Inundate Parts of Parks |
|---|---|---|
| Name of Park | Distance from River Mouth (km) | |
| Ai-Ais Nature Reserve (Namibia) | 108 to 185 | Kabies |
| Richtersveld Nature Reserve (South Africa) | 102 to 220 | Kabies |
| Augrabies Falls National Park | 586 to 630 | All dams upstream of Onseepkans (depending on the heights of the dams) |

## 4.10 Powerlines

Four powerlines that cross the Orange River along the common border have been identified. Three of the powerlines are utilised by the power supply utilities Nampower in Namibia, and ESKOM in South Africa, to import or export electrical power, as the case may be. The fourth powerline (a few kilometres upstream of Alexander Bay) was observed, while flying along the Orange River during a site visit in September 2002, and is also indicated on the 1:50 000 topographical map for the area. Details of the power lines are given in **Table 4.8** below, and indicated in **Appendices C1**, **C4** and **C5**. There are also lower voltage powerlines that distribute electrical power to consumers along the river (for example at Noordoewer, Vioolsdrif and Aussenkehr), but these have not been indicated in the table or in the appendices.

**Table 4.8: Locations of High-voltage Powerlines Crossing the Orange River along the Common Border**

| Location | | Longitude | Voltage | Dams that may Inundate Powerlines |
|---|---|---|---|---|
| Farm or town in vicinity of powerline | Distance from river mouth | | | |
| Oranjemund | 19 | 16º 37' | (not known) | (none) |
| Rosh Pinah | 102 | 16º 53' | 66 kV | (none) |
| Noordoewer | 275 | 17º 37' | 22 kV | (none) |
| On farm Kabis | 380 | 18º 31' | 220 kV | Vioolsdrif |

# 5. PRE-SCREENING OF DEVELOPMENT OPTIONS

## 5.1 Purpose of Sub-Task

This sub-task is numbered 4.1b. The purpose of this task is to evaluate the development options identified in Task 4.1a against the specified pre-screening factors listed below with a view to identifying the most favourable sites for the Preliminary Design Task (Task 4.1d).

## 5.2 Pre-screening Factors

Factors considered in the pre-screening of the various potential dam sites include:

**Site considerations:**

- topography of the site and basin;
- geological conditions;
- construction materials and borrow areas;
- storage capacity potential;
- whether the dam should be a small re-regulating dam or a large storage dam;
- design floods and spillway arrangements;
- seismic characteristics;
- river diversion during construction;
- considerations with regard to site establishment; and
- access roads.

**CONTRIBUTION TO THE SYSTEM YIELD**

**Social and environmental impacts:**

- potential social impacts; and
- potential environmental impacts.

**Other factors:**

- proximity and location with respect to major demand centres;
- international borders;
- possibility of hydro-power generation;
- proximity to power lines;
- flooding of existing infrastructure and its relocation (including feasibility, costs and

social impacts);

- flooding of existing or potential irrigation areas;
- flooding of mining and prospecting licence areas;
- flooding of areas of archaeological importance;
- likely sedimentation rate; and
- potential effects on water quality.

## 5.3 Options Upstream of the Common Border

### *5.3.1 Potential Development Options*

The eight potential development options identified in the ORRS that are of relevance to the LORMS are listed in **Table 5.1**. During the ORRS, a pre-screening was performed on these options and the reasons why they were either omitted or recommended for further detailed analysis are also listed.

**Table 5.1: Details of Development Options Identified in the ORRS Upstream of the Common Border**

| Development Option | Main Purpose | Comments |
|---|---|---|
| Havenga Bridge Dam | • Alleviation of abstraction problems experienced by irrigators between Vanderkloof Dam and Prieska. | **Recommended** for further detailed analysis since it provides a very low cost / yield relationship. |
| Elandsdraai Dam | • Minimisation of abstraction problems by providing a more constant base flow.<br>• Increase in hydropower generation. | **Recommended** for further detailed analysis since irrigators will benefit through less abstraction problems. |
| Eskdale Weir | • Increase hydropower.<br>• Increase irrigation development in the Plooysburg area. | **Omitted** since Torquay Dam provides similar benefits and was found to be a more cost effective and practical option. |
| Hereford Weir | • Increase hydropower.<br>• Increase irrigation development in the Douglas area. | **Omitted** since Torquay Dam was found to be a more cost effective and practical option. |
| Torquay Dam | • Regulation of seasonal irrigation supply from Vanderkloof Dam to increase Hydro Power generation.<br>• Reduction in losses due to excessive releases from Vanderkloof Dam.<br>• Increase of irrigation development in the Plooysburg and Douglas areas. | **Recommended** for further detailed analysis since:<br>• The site located in close proximity to possible new irrigation areas.<br>• The cost/yield ratio is attractive.<br>• Hydropower possibilities exist. |
| Lanyonvale Dam | • Flood absorption and attenuation.<br>• Regulation of seasonal irrigation supply from Vanderkloof Dam to increase Hydro Power generation. | **Omitted** since a new Boegoeberg Dam is considered to be a more cost effective and practical option. |
| Hospital Dam | • Flood absorption and attenuation.<br>• Regulation of seasonal irrigation supply from Vanderkloof Dam to increase Hydro Power generation. | **Omitted** since a new Boegoeberg Dam is considered to be a more cost effective and practical option. |
| New Boegoeberg Dam | • Regulation of river flow to improve supply of Lower Orange River water.<br>• Reduction in water losses due to excessive releases at Vanderkloof Dam.<br>• Increase in water yield.<br>• Increase in hydropower.<br>• Better utilisation of spills from the Vaal River System. | **Recommended** for further detailed analysis since it offers:<br>• An attractive cost / yield ratio.<br>• Excess Vaal River water can be utilised.<br>• Ideal location regarding regulation to Upington area. |

The following options for dams upstream of the common border were carried through to the Pre-Feasibility Phase of the ORRS:

- Torquay
- Boegoeberg

Due to time and budget constraints only the yield related options were analysed as part of the ORRS with the result that those options intended as re-regulation options for the hydropower releases from Vanderkloof Dam (Havenga Bridge and Elandsdraai) were excluded from the Pre-Feasibility Phase.

### *5.3.2 Cost Analysis and Economic Analysis*

The cost analysis of the various development options was undertaken by using the basic principals developed for the VAPS. This included preliminary designs and cost models for each option followed by the calculation of unit reference values (URVs). The methodology of calculating the URVs is described in **Section 9**.

Quantities were taken from 1:10 000 orthophoto contoured maps or from detailed surveys (1:2 000) if available, as well as from 1:50 000 contour maps. The economic calculation basically determined the net present (1994) cost associated with the capital expenditure, as well as the maintenance and operation costs. The water yield from a specific scheme (with growth according to the future water requirements) expressed in terms of a net present value was then used to calculate the URV of the scheme in R/m$^3$ yield (or c/m$^3$). In general, the economic calculations were performed in the following manner:

- An 8% discount rate was used (sensitivity was also evaluated with 6% and 10% discount rates);
- The phasing of schemes, and components thereof, were scheduled in accordance with the demand projections for the Vaal Basin and required filling times of the major proposed dams;
- The costs of the inter-basin transfer component of the various options were only included for the combined dam development options;
- Costs of land and betterment were included where applicable; and
- Social costs and impacts were not included in the economic assessment, but were taken into account in the overall assessments.

The results of the analyses (excluding dams along the common border) are summarised in **Table 5.2**.

**Table 5.2: Single Dam Development Options considered in the Pre-feasibility Phase of the ORRS**

| No. | Option | Purpose | Net Capacity (mil. m³) | Capital Cost (R.million) | Excess Yield (mil. m³/a) | URV (c/m³) (@ 8%) |
|---|---|---|---|---|---|---|
| 5a | Torquay Dam 1 020 m | Reduce operating losses | 50 | 95 | 115* | 79 |
| 5b | Torquay Dam 1 040 m | Yield increase | 500+ | 202 | 70 | 289 |
| 5c | Torquay Dam 1 050 m | Yield increase | 800 | 330 | 128 | 257 |
| 6a | At existing site Boegoeberg Dam 894 m | Reduce operating losses | 90 | 63 | 130* | 49 |
| 6b | New Boegoeberg Dam 894 m | Reduce operating losses | 90 | 84 | 130* | 65 |
| 6c | New Boegoeberg Dam 909 m | Yield increase | 470 | 199 | 14 | 1444 |
| 6d | New Boegoeberg Dam 920 m | Yield increase | 1 900 | 313 | 286 | 117 |

* Indication of the saving in operating losses which can be gained when utilising the given dam as a re-regulation dam only

\+ Required capacity at Torquay Dam to change hydro-power based releases from Vanderkloof Dam to the required downstream irrigation demand based releases pattern

### *5.3.3 Conclusions of the ORRS*

The ORRS concluded that most of the initial development options considered in the Orange River Basin could be eliminated from further consideration on financial, social, engineering or environmental grounds. Only a small number of options remained as possible future developments, however, it was not possible to make firm recommendations at that stage.

In all of the remaining options, it was considered necessary to create some form of operational storage along the Orange River at either Vioolsdrif or Boegoeberg. Both options had similar URVs and it was not possible to eliminate either of them during the Pre-feasibility Phase of the ORRS.

### 5.3.4 Conclusions of the Review of the ORRS

No reason could be found to differ from the conclusion of the ORRS that the most feasible option for the construction of a new dam upstream of the common border was the New Boegoeberg Dam. However, the ORRS Report did not provide sufficient motivation for the choice of the Vioolsdrif Dam as the most feasible site for the construction of a dam along the common border. This was known beforehand though, and is one of the reasons that the ToR states that the emphasis for the Dam Development Options of this study (i.e., the LORMS) shall be to investigate dam sites along the common border.

## 5.4 Options along the Common Border

### 5.4.1 Potential Development Options

For ease of reference all the potential dam sites along the common border that were identified in this study, as well as those identified in the ORRS, are repeated in **Table 5.3**. The locations are shown on the 1:250 000 maps in **Appendices C2** to **C7**. A preliminary pre-screening was done on these options with a view to eliminate those options that were clearly flawed from an engineering, social or environmental viewpoint.

**Table 5.3: Potential Dam Sites identified along the Common Border**

| Name of Dam Site | Appendix | Comments |
|---|---|---|
| Kabies | C2 | Omitted. Downstream demands too low. Inundate parts of Richtersveld National Park. |
| Grootpens A | C3 | Omitted. Inundate irrigation areas at Aussenkehr. |
| Grootpens B | C3 | Omitted. Inundate irrigation areas at Aussenkehr. |
| Aussenkehr | C3 | Omitted. Too far downstream for Vioolsdrif demands and too far upstream to capture Fish River water. |
| Vioolsdrif A | C4 | |
| Vioolsdrif B | C4 | |
| Vioolsdrif C | C4 | |
| Vioolsdrif D | C4 | |
| Kambreek | C6 | Omitted. Considered inferior to Vioolsdrif A site from engineering and geological viewpoint in ORRS. |
| Coboop A | C6 | Omitted. Low potential storage due to steep river. |
| Coboop B | C6 | Omitted. Low potential storage due to steep river. |
| Coboop C | C6 | Omitted. Low potential storage due to steep river. |
| Beenbreek | C7 | Omitted. Dam site much inferior to other sites, and low potential storage due to steep river. |
| Yas | C7 | |
| Komsberg | C7 | |

### *5.4.2 Cost Analysis*

In order to compare the remaining options, approximate dam cost versus height curves as well as storage capacity curves was prepared.

Due to the fact that a dam on the LOR would have to be able to pass floods in excess of 25 000 $m^3/s$, only mass concrete dams were considered for the purposes of pre-screening in order to incorporate overflow spillways in the dam structures.

The width of the particular site was measured at each contour interval using the 1:50 000 topographical maps. In most cases the contour intervals were 20 m with a few isolated cases of 10 m intervals. These figures were entered into a spreadsheet, as well as the all-in unit rate for mass concrete dams. The all-in rate was obtained by multiplying the mass concrete rate from the Design and Cost Criteria in **Appendix A** by a factor of 4.5 to provide an indication of the total cost of the particular dam. The factor of 4.5 was based on the approximate ratio of concrete cost to total cost for the Boegoeberg and Vioolsdrif Dams as presented in the ORRS Report. In this way, it was possible to determine the cost of each 'layer', and therefore also the cost of the whole wall. In order to allow for freeboard requirements, it was assumed that the total height of the dam wall was 10 m above the full supply level (FSL).

Various ways of determining the surface areas of reservoirs were investigated, such as:

- digitizing the contours on the 1:50 000 maps;
- by producing vector files from Digital Elevation Models (DEMs), which are available from the Directorate: Survey and Mapping in Mowbray;
- by scanning the so-called contour separates of the 1:50 000 maps; and
- by utilizing so-called vector files in 'dxf' format, of the 1:50 000 topographical maps.

As the 'dxf' files were available for the whole length of the Orange River along the common border, the latter method was utilized to determine the areas between contours by means of computer-aided draughting software.

The approximate dam cost versus height curves, as well as the storage capacity curves was consolidated into graphs of dam cost versus storage capacity to allow comparison between the remaining options. The graphs are shown in **Figure 5-1**, **Figure 5-2** and **Figure 5-3**, and compare the Vioolsdrif A, Yas and Komsberg sites. The Vioolsdrif B, C and D sites were omitted from this comparison as they are considered to be variations of the Vioolsdrif site in general, which will receive further attention during the Preliminary Design Task if the Vioolsdrif site is selected.

The layouts and cross-sections of the Vioolsdrif A, Yas and Komsberg sites are shown in **Appendices D** and **E**, respectively.

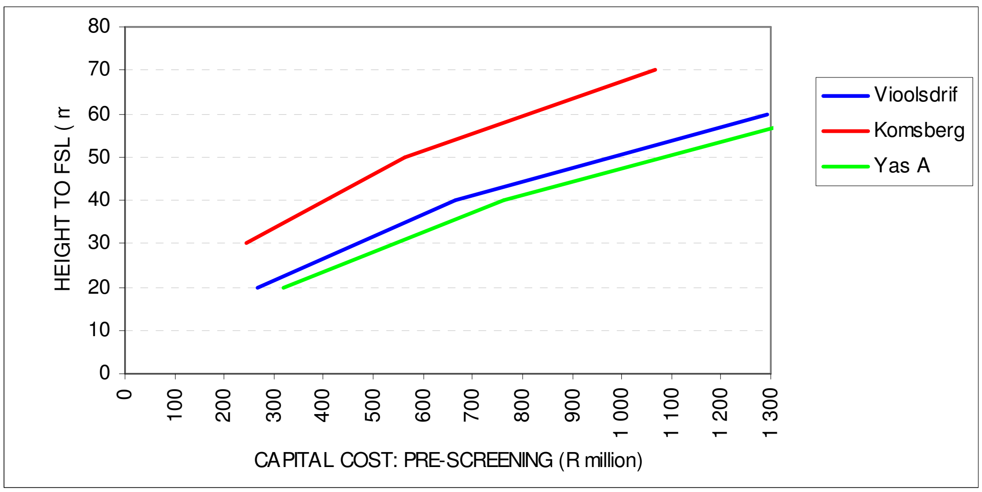


**Figure 5-1: Capital Cost (Comparative) of Dam Construction versus Dam Height**

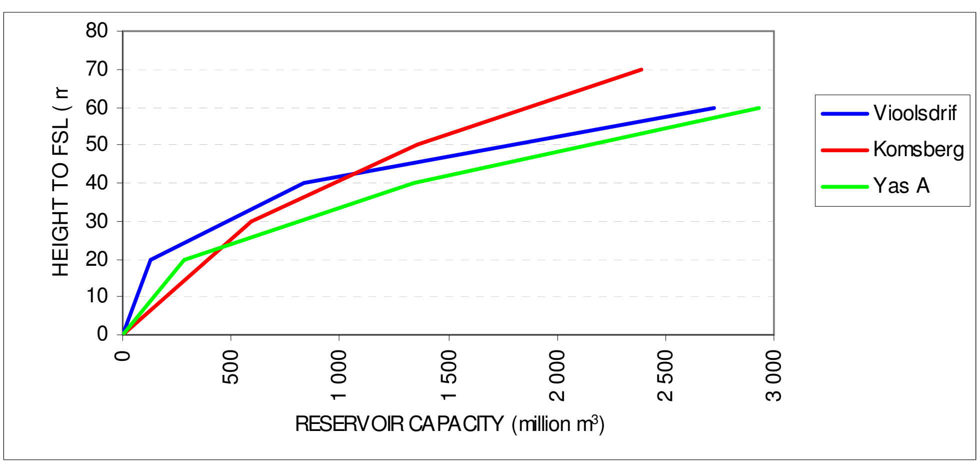


**Figure 5-2: Reservoir Capacity versus Dam Height**

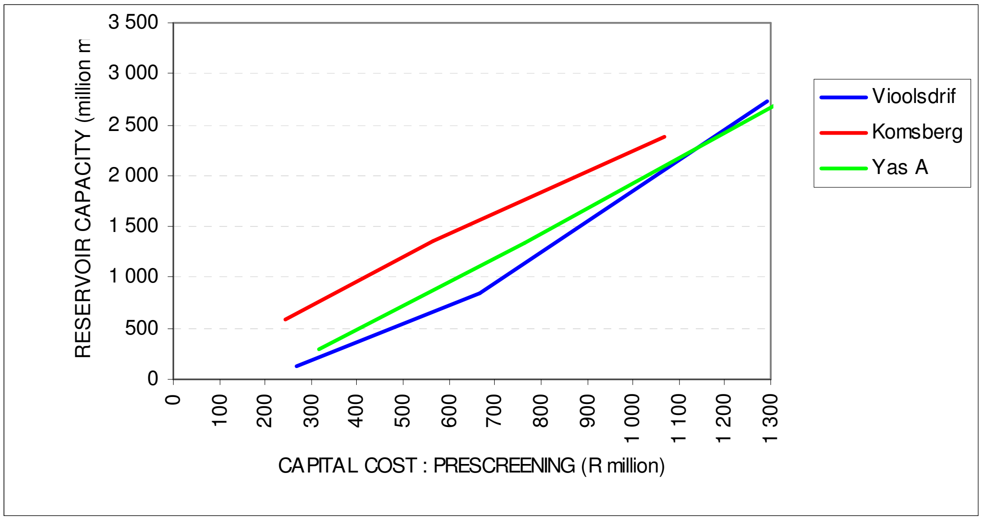


**Figure 5-3: Capital Cost (Comparative) of Dam Construction versus Reservoir Capacity**

### *5.4.3 Evaluation against Pre-screening Criteria*

In order to evaluate the remaining options against all the pre-screening criteria, a matrix was compiled as shown in **Table 5.4**. The table takes into account all the potential impacts discussed in **Section 4**.

## Table 5.4: Pre-screening

| Pre screening Factor | Dam Site | | |
|---|---|---|---|
| | **Vioolsdrif A** | **Yas** | **Komsberg** |
| **Site Considerations** | | | |
| Topography of site and basin | Moderately good dam site | Good dam site | Very good dam site - narrow valley |
| Geological conditions | Only the Vioolsdrif Dam site was investigated (in the ORRS Study) and geological conditions can therefore not be used as a factor for pre-screening purposes. | | |
| Construction materials & borrow areas | Only the Vioolsdrif Dam site was investigated (in the ORRS Study) and this pre-screening factor can therefore not be used as a factor for pre-screening purposes. | | |
| Storage capacity potential | Potential storage capacities all exceed the maximum volume that can be utilized effectively | | |
| Small re-regulating dam or large storage dam | All sites are suitable for either a small re-regulating dam, or a larger storage dam. | | |
| Design floods & spillway arrangements | Design floods similar due to relatively great distance to main catchment areas | | |
| | Mass concrete overflow | Mass concrete overflow plus possible by-wash | Mass concrete overflow |
| Seismic characteristics | All of the sites are situated in a low seismic risk area. | | |
| River diversion during construction | For pre-screening purposes only mass concrete gravity dams were considered, and river diversion considerations are therefore identical. | | |
| Considerations to site establishment | Not considered during pre-screening. | | |
| Access roads | Access is difficult due to steep valley sides | 1:50 000 maps do not indicate roads in the immediate vicinity of the dam sites | |
| | | | |
| **Contribution to the system yield** | Considered to be similar for all sites due to negligible additional inflow from catchment areas in the vicinity of these dam sites. | | |
| **Social and environmental impacts** | | | |
| Potential social impacts | Social impacts of the individual sites were not investigated, but the social impacts of the sites should not differ from one another significantly. | | |
| Potential environmental impacts | Considered relatively low | Inundation of parts of the Augrabies Falls National Park | |

| Pre-screening Factor | Dam Site | | |
|---|---|---|---|
| | Vioolsdrif A | Yas | Komsberg |
| **Other factors** | | | |
| Proximity / location to major centres | ~ 20 km from Vioolsdrif / Noordoewer | ~ 60 km from Onseepkans | ~ 90 km from Onseepkans |
| International borders | Situated on the border between Namibia and South Africa. | The above dams and other dams constructed in the vicinity will have a lesser effect on international borders as water pushes up past 20° longitude. | |
| Possibility of hydro-power generation | There is the possibility of hydro-power generation at all sites investigated. | | |
| Proximity to powerlines | 20 km (line at Vioolsdrif / Noordoewer) | 200 km (line on farm Kabis) | 240 km (line on farm Kabis) |
| Flooding of existing infrastructure | No flooding of major infrastructure | | |
| Flooding of irrigation areas: existing and potential | Potential flooding of irrigation areas in the vicinity of the river. | | Smaller irrigation areas flooded |
| Flooding of mining and prospecting license areas | On Namibian side of border, all dams flood areas over which mining and prospecting licenses have been issued. Not much difference between one dam and the other. | | Smaller areas flooded |
| Flooding of areas of archaeological importance | The conclusions of the desk study are that not many detailed investigations had been carried out to date and further investigations would have to be carried out for particular sites in the case of dam construction. | | |
| Sedimentation rate | The difference is sedimentation rates between the different sites was not investigated but is not considered to be significant enough to influence a choice between the sites. | | |
| Potential effects on water quality | The difference on the effects on the water quality between the different sites was not investigated, but is not considered to be significant enough to influence a choice between the sites. | | |
| | | | |
| **Cost** | Moderate cost | Similar to Vioolsdrif | Lowest cost of all sites |

### *5.4.4 Discussion of Pre-screening Analysis*

#### 5.4.4.1 Vioolsdrif A

This dam site is situated close to existing infrastructure, but access to the site will be difficult due to the steep valley sides. The dam will inundate areas over which mining and prospecting licenses have been issued, over most of the distance that the impounded water pushes up the river.

#### 5.4.4.2 Yas

This dam site is situated approximately 54 km downstream of the border at 20° longitude. As in the case of the Komsberg site, much of the water stored by the dam will be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure, or powerlines.

A dam at this site would have a similar cost to dams at the Vioolsdrif sites.

5.4.4.3 Komsberg

As can be seen from **Appendix C7**, this dam is situated approximately 7 km downstream of the border at 20° longitude. Most of the water stored by the dam will therefore be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park, which is situated along the northern side of the river. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure or powerlines.

Based on the 1:50 000 mapping, this site was found to be the most economical site along the common border for the construction of a dam for the range of reservoir capacities under consideration. However, the extent of the inundation of the Augrabies Falls National Park remained of concern.

### *5.4.5 Conclusions*

Based on the pre-screening, the following conclusions were made:

- The Yas Dam site does not offer any significant cost benefits over the Vioolsdrif site and will inundate parts of the Augrabies Falls National Park. It was therefore excluded from further analysis.
- From a capital cost point of view (as defined in this report), the Komsberg site is more cost-effective than the Vioolsdrif site for the construction of either a smaller re-regulating dam or a larger dam to improve the yield of the system. The allowable inundation of the Augrabies Falls National Park, however, still had to be determined.

The nett result of the pre-screening was that both the Viooldrif A and the Komsberg Dam sites were taken to a Decision-making Workshop, as discussed in the next section.

# 6. ASSESSMENT OF PRE-SCREENED DEVELOPMENT OPTIONS

## 6.1 Initial Selection

In the pre-screening process, the number of dam sites that could possibly be carried forward to the preliminary design stage, was reduced to the following sites:

Upstream of 20° longitude (i.e., upstream of the common border):

- New Boegoeberg Dam

Downstream of 20° longitude (i.e., along the common border):

- Vioolsdrif Dam
- Komsberg Dam

These three possible options were investigated in more detail in order to make more accurate cost estimates, determine yields and assess benefits and impacts. The options were then evaluated at a Decision-making Workshop on 13 and 14 October 2003 by a team consisting of the Client, selected stakeholders and the Consultant.

Prior to the workshop, the following activities were carried out on the three dams:

- A yield analysis was carried out in order to determine the required storage capacities for specified yields (see Section 4.6 in the report titled 'Hydrology, Water Quality and Systems Analysis : Volume A – Systems Analysis).
- A sedimentation analysis was carried out on the New Boegoeberg and Vioolsdrif sites in order to estimate the sedimentation volumes (see **Section 7** of this report).
- A financial analysis was carried out in order to determine the unit reference values of the dams of various storage capacities. These were based on costing at August 2002 prices and URVs at base year of 2003.

The pertinent data for the New Boegoeberg, Vioolsdrif and Komsberg Dam sites is summarised in **Table 6.1** and the URV calculations included in **Appendix I**.

**Table 6.1: Pertinent Values for the Preferred Sites for Re-regulating Dams**

| | New Boegoeberg | Vioolsdrif | Komsberg |
|---|---|---|---|
| Proposed dam size (million $m^3$) | 163 | 260 | 260 |
| Unit reference value (@ 8%) (R/$m^3$) | 0,35 | 0,26 | 0,24 |
| Saving in operational losses (million $m^3$/a) | 62 | 170 | 126 |

At the workshop, it was decided that the Vioolsdrif and Komsberg Dam sites were preferred to the New Boegoeberg Dam site for the following reasons:

- Significantly lower URVs.
- Significantly larger saving in operational losses.

## 6.2 Komsberg Dam Site

Due to the fact that dams for all heights under consideration at the Komsberg site would inundate parts of the Augrabies Falls National Park, it was decided that the Komsberg site should not be considered unless there were significant cost advantages. The cost estimates of the Vioolsdrif and New Boegoeberg Dam sites had been done on 1:10 000 mapping with 5 m contours, whilst that of the Komsberg Dam site was done on 1:50 000 mapping with 20 m contours. It was therefore decided that 1:10 000 mapping should also be prepared for the Komsberg site.

Aerial photography at a scale of 1:50 000 was obtained from the Directorate: Surveys and Mapping in Mowbray near Cape Town for Job No 1062 of 2002. A plan at a scale of 1:10 000 was then prepared for the Komsberg Dam site.

Based on the above mapping, the quantities for the Komsberg Dam site were recalculated. The URV for a dam with a capacity of 260 million $m^3$ increased to R0.28/$m^3$.

The river bed levels downstream of the Augrabies Falls were also checked by using the DEMs of the area. The DEMs consist of x, y and z co-ordinates on a grid of 25 x 25 m obtained from aerial photography, and is produced during the production process of 1:10 000 orthophoto maps (no mapping is available as yet).

The river bed level at the Komsberg Dam site is at approximately RL 430.8 m (from the 1:50 000 mapping). Above a FSL of approximately RL 432 m, water will start pushing up into the Augrabies Falls National Park, and the rapids downstream of the Falls will start to be inundated at levels above RL 450 m. The FSL for the proposed re-regulating dam will be at approximately RL 446 m.

## 6.3 Ecological Assessment

After the Workshop, field visits were made to the Vioolsdrif and Komsberg areas in order to carry out a vegetation study and ecological and archaeological assessments. These studies came to the following conclusions:

### *6.3.1 Vegetation Study*

- A dam site in the Vioolsdrif area would overall affect a less developed stretch of riparian landscapes and habitat, but stretches of the river are invaded by alien vegetation.
- A dam site in the Komsberg area would affect large stretches of relatively pristine riparian woodlands, though interrupted by agricultural developments.
- Both dam options would inundate approximately 50 to 70 km of riparian habitat in a presently little developed area, which is a major environmental impact.

### *6.3.2 Ecological Assessment*

The ecological assessment was done to provide a coarse-level assessment, based on readily available information, of the potential ecological implications on the LOR of a dam situated at the Vioolsdrif and Komsberg Dam sites (the Boegoeberg Dam site was also evaluated to provide an overall assessment).

From the assessment it was concluded 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 higher dam walls.
- Dams with lower dam walls have relatively less impact than those with higher dam walls.

### 6.3.3 Archaeological Assessment

The archaeological assessment was carried out on the Vioolsdrif and Komsberg Dam sites.

From the assessment it was concluded that:

- Major tributary stream confluences are important archaeological localities, especially in the vicinity of springs and seepages.
- The present banks of the Orange River are relatively unimportant localities.
- River crossings and access routes are historically important features.
- Recent grave sites tend to be located on the banks of the Orange River.

## 6.4 Conclusions

A summary of the assessment is presented in the **Table 6.2**.

**Table 6.2: Summary of Assessment of Vioolsdrif and Komsberg Options**

| Dam Sites | Vioolsdrif | Komsberg |
|---|---|---|
| **Issues** | | |
| Potentially serious implications of any raising of the dam in future | None | Inundation of the rapids downstream of the Augrabies Falls. |
| Impact on Augrabies Falls and National Park | None | Dam basin inside the Park and potential sediment and back water affects in rapids |
| Saving in operational losses (million $m^3$/a) | 170 | 126 |
| Ecological | Would have the most impact relative to the other options. | Would have a lower impact than the Vioolsdrif Dam option. |
| Archaeological | Would have the greater impact on archaeological remains. | Would have a lesser impact on archaeological remains than Vioolsdrif. |
| Vegetation | Would overall affect a less developed stretch of riparian landscapes and habitats. | Would affect large stretches of relatively pristine riparian woodlands, though interrupted by agricultural developments. |
| Unit reference values (R/$m^3$) | 0.26 | 0.28 |

The above information was presented to the Client and it was decided that the development of a re-regulating dam at the Vioolsdrif Dam site was preferred to the Komsberg Dam site.

# 7. SEDIMENTATION ANALYSIS

## 7.1 Introduction

In order to obtain an estimate of the expected sedimentation rates for possible future reservoirs at Boegoeberg and Vioolsdrif, the Consultant commissioned Professor Albert Rooseboom to perform a sedimentation analysis. The Komsberg reservoir was not included as the two above dams would cover the extremities of the study area. The report is attached hereto as **Appendix G**.

A summary of the report is given below.

## 7.2 Summary of Report

### *7.2.1 Introduction*

Sediment loads that will be carried into new reservoirs can be predicted either from sediment sampling on river streams or from calibrated sediment yield maps.

As part of the ORRS, a report titled "Sedimentation of Reservoirs in the Orange River Basin" was prepared. This report deals inter alia with expected sedimentation rates for reservoirs at Boegoeberg and Vioolsdrif. These predicted rates were based on the most recent (1992) sediment yield map of South Africa. The accuracy of this map is extremely low for the LOR area due to a lack of reliable calibration data. It was therefore decided to investigate alternative approaches to obtain more reliable values for the expected sedimentation rates. In a first attempt in 1998, Prof Rooseboom used earlier sediment sampling data to obtain estimates for sedimentation rates that are independent of the sediment yield maps. As this approach was unconventional, its validity was re-considered and justification for its use is being provided in this report.

### *7.2.2 Sediment Loads of the Orange River*

#### 7.2.2.1 Stream Sampling Data for the Orange River

Sediment loads in South African rivers are currently being recorded mainly by means of regular re-surveys of existing dam basins. Prior to the construction of the majority of dams in South Africa, where sediment accumulation could be measured, stream sampling was undertaken on a number of tributaries of the Orange River (as well as other rivers).

From data obtained from the Prieska and Upington stations for the period 1929 - 1969, it was deduced that the average sediment load decreased with time. Over the same time period, the average sediment concentrations did not vary significantly. The reduction in the sediment load can therefore be attributed to the reduction in the mean annual runoff (MAR) due to the construction of major dams in the catchment.

It is therefore concluded that in the case of the LOR, sediment concentration values recorded along the river, provide a more reliable basis for estimating sediment loads at Boegoeberg and Vioolsdrif than the sediment yield maps.

7.2.2.2 Sediment Loads Derived from Reservoir Re-surveys

There is no information available from reservoir re-surveys that can be used to calibrate the zones of the sediment yield map of South Africa, which fall within the effective catchments of Boegoeberg and Vioolsdrif, with an acceptable degree of accuracy. Although the base sediment yield map indicates that sediment yield rates for these catchments will be low, it is not possible to estimate sediment yields for this area accurately enough, given the large areas involved.

### *7.2.3 Estimated Sedimentation Rates for Future Reservoirs at Boegoeberg and Vioolsdrif*

On the conservative assumption that the sediment load under natural (pre-dam) conditions constituted 0,6% by mass, then the corresponding sediment loads under "natural" conditions amount to 64 million tonnes per annum at Boegoeberg and 63 million tonnes per annum at Vioolsdrif. According to the current flow conditions the average annual loads will be 29 million tonnes at Boegoeberg and 25 million tonnes at Vioolsdrif. The first two figures compare well with early-recorded values and the latter values compare realistically with the average recorded load of 34 million tonnes/a around 1964.

Whilst it is likely that sediment loads will decrease further this cannot be guaranteed and the above figures of 29 and 25 million tonnes per annum must be taken as the maximum foreseeable loads. It is reasonable to assume that an average sediment concentration of 0,4% is a more probable value than 0,6%. On this basis, the likely average annual sediment loads at Boegoeberg and Vioolsdrif amount to 20 and 17 million tonnes/a, respectively.

**Table 7.1: Estimated 50-year Sediment Volumes for Storage Reservoirs at Vioolsdrif and Boegoeberg**

| Dam | Total Storage (million $m^3$) | Sediment Load (million tonnes/a) | 50-year Sedimentation Volume (million $m^3$) |
|---|---|---|---|
| Vioolsdrif | >1220 | 16,6 (25 max) | 602 (903 max) |
| Boegoeberg | >1430 | 19,6 (29,5 max) | 711 (1067 max) |

If a storage reservoir is to be constructed at Boegoeberg, the best estimate of the sediment load that will be entering the reservoir is 19,6 million tonnes per annum. With a trap efficiency of 98%, this means that the 50-year sediment volume will be 711 million $m^3$.

Similarly, if a storage reservoir is to be constructed at Vioolsdrif, the annual sediment load would be 16,6 million tonnes and the 50-year sediment volume 602 million $m^3$.

The maximum sediment load and volume values in the table are the maximum foreseeable values. A re-regulation weir at Vioolsdrif with a total storage capacity of 260 million $m^3$ will initially trap in the order of 80% of the incoming sediment load. Similarly, a weir at Boegoeberg with a total storage capacity of 163 million $m^3$ will trap roughly 70% of the incoming sediment load. A weir at either of these positions will therefore lose a large proportion of its storage capacity within 10 years unless it is purposefully designed and operated.

# 8. PRELIMINARY DESIGN

## 8.1 Vioolsdrif Dam Sites

During the ORRS, three possible dam sites were identified between 9 and 10 km upstream of the existing Vioolsdrif Weir. The uppermost site (referred to as Vioolsdrif A in this study) was eventually chosen for inclusion in the ORRS Report.

A further two sites were identified 1.5 and 5 km upstream of the confluence of the Haib and Orange Rivers (referred to as Vioolsdrif B and C, respectively in this study). A further site (Vioolsdrif D) situated 8.5 km upstream of the confluence, was identified in this study. The location of the sites is shown in **Appendix C4**.

The dam sites upstream of the confluence with the Haib River are some 50 to 150 m wider than the Vioolsdrif A site. It offers some advantage with regard to easier access and the wider cross-section could be of benefit to accept a wider spillway. These aspects should be investigated during the detail site selection phase. For the purposes of this report, the Vioolsdrif A Dam site was retained as the preferred site due to the smaller cross-sectional area and also to facilitate comparison with the ORRS work.

## 8.2 Available Mapping

All the work in the ORRS at the Vioolsdrif Dam sites was based on the 1:50 000 topo-cadastral maps of the area.

The 1:50 000 mapping was retained to compile the storage capacity curve for the site (see **Section 5.4.2**). The curve is shown on **Figure H.1** in **Appendix H**.

In order to provide a better estimate of the construction quantities, aerial photography at a scale of 1:60 000 was obtained from the Directorate: Surveys and Mapping in Mowbray near Cape Town for Job No 997 of 1997. Survey plans at a scale of 1:10 000 with 5 m contours were then prepared for the Vioolsdrif A Dam site, as well as the Vioolsdrif B to D Dam sites.

Due to the lack of sufficient control points in the vicinity of the dam sites, the overall positioning and datum of the 1:10 000 mapping could not be guaranteed. In order to facilitate comparison with the storage capacity curve generated from the 1:50 000 mapping, the river bed level at the Vioolsdrif A Dam site was adjusted to that of the estimated 1:50 000 level. If the Vioolsdrif Dam sites were to be investigated further, more accurate mapping based on dedicated aerial photography should be undertaken.

## 8.3 Geology

The foundation consists of granodiorite of the intrusive Vioolsdrif site, of Mokolian age. Intermittent, narrow bands of alluvium occur on both banks of the river.

The lower section of the left flank consists of large outcrops of black, fine-grained granodiorite. The middle to upper section consists of coarse-grained granodiorite intermixed with mica, which weathers to a flaky schist.

The overburden on both flanks consists of broken rock of varied description and takes the form of a thin, patchy layer of rubble. Excavation depths of less than 1 to 2 m are expected to expose suitable foundation rock.

The river section consists of thick alluvial deposits of boulders and sand. It is anticipated that sound material will be found at an excavation depth of approximately 4 m.

Coarse aggregates can be produced from local sources near the dam site consisting of quartzites, diorites and other rock types. Due to the narrow valley section in which the dam site is located, the alluvial sand is not plentiful. Fine aggregates will therefore also have to be produced by crushing of the local rock.

Photographs of the dam site are presented in **Appendix H.**

## 8.4 Flood Determination

### *8.4.1 Flood Magnitudes*

In terms of the Guidelines for Sizing of Mass Concrete Dams (see **Section 3.2** in **Appendix A**), the flood magnitudes are to be based on the RMF concept.

In the ORRS, the regional maximum flood (RMF) was estimated to be 18 930 $m^3/s$. This was based on an effective catchment area of 404 000 $km^2$ and a Francou Rodier k-value of 2,8. In accordance with the Guidelines on Safety in Relation to Floods (SANCOLD, 1991), the safety evaluation discharge (SED) is based on the RMF for a region one step higher numerically than that in which the study catchment lies. For the Vioolsdrif Dam site, this equates to a Francou Rodier k-value of 3.4. The SED was then calculated to be 26 300 $m^3/s$ (similar to the figure in the ORRS).

The recommended design discharge (RDD) is based on the 1:200-year recurrence interval (RI) flood. An approximate value is obtained by multiplying a factor from TR137 (Kovacs, ZP, 1988) with the RMF. The RDD comes to 14 250 $m^3/s$.

The diversion flood for a concrete dam is based on the 1:10-year RI flood. The factors in TR137 also provide estimates of 1:20-year RI floods. The diversion flood was estimated to be half that of the 1:20-year RI flood and comes to 3 000 $m^3/s$.

### *8.4.2 Flood Attenuation*

Due to the very large catchment area, insignificant flood attenuation is anticipated.

### *8.4.3 Freeboard*

The freeboard requirements are set out in **Table 8.1** and are based on a spillway length of 375 m (see **Section 8.5**).

**Table 8.1: Calculation of Freeboard**

| Characteristic | Freeboard Requirement (m) |
|---|---|
| **For recommended design flood**: | |
| Overflow depth for 1:200 year flood of 14 250 $m^3/s$ | 6.89 |
| Wave height and run-up | 2.73 |
| Wind set-up | 0.25 |
| Surges | 0.50 |
| **Total** | **10.37** |
| **For safety evaluation discharge** | |
| Flood magnitude = 26 300 $m^3/s$ | **10.37** |

For the preliminary design, a total freeboard of 10 m was used.

## 8.5 Spillway Design

Due to the high flood magnitudes that need to be passed over the dam, the complete base width of the valley of 375 m will be used as spillway.

The flood surcharge was calculated with a discharge coefficient of 2.1 and the results are shown in **Table 8.1**.

A design head of 7.5 m was selected for the ogee to provide a ratio of 1.33 between the maximum head during the SEF and the design head to limit the potential sub-atmospheric pressures on the crest during the SEF to about one-half of the design head. In this way the discharge capacity of the ogee is increased over the full range of design flows *(Design of Small Dams, 1987)*.

The necessity for a stilling basin was briefly investigated. For unit flows of 12 to 15 $m^3$/s/m of spillway, steps on the downstream face (as associated with rollcrete construction) can be used to dissipate energy and eliminate the need for a full stilling basin *(Mason, PJ, 2004)*. This will cater for flood discharges up to approximately one-third of the RDD.

For higher discharges, the energy dissipating capability of the steps reduces due to the development of skimming flow over the steps. However, due to the narrow river valley and high flood discharges the estimated tailwater level will provide sufficient water depth to force a hydraulic jump immediately downstream of the dam.

The estimated stilling basin length for the RDD is 50 m. The preliminary design allows for an apron slab of 20 m long and the clearing of the riverbed of all loose material down to bedrock for a further 30 m. This will have to be re-assessed during the detail design stage.

## 8.6 Dam Size

The preliminary design was done for a dam with the following parameters:

- Total storage capacity 260 million $m^3$
- Allowance for sedimentation 150 million $m^3$
- Live storage capacity 110 million $m^3$
- Wall height to non overspill crest (NOC) 35.1 m

| | |
|---|---|
| • River bed level | reduced level (RL) 176.4 m (approximately) |
| • FSL | RL 201.5 m |
| • NOC | RL 211.5 m |
| • Wall height to FSL (i.e., spillway height) | 25.1 m |
| • Total crest length | 485 m |

The allowance for sedimentation was based on a sediment load of 16.6 million tonnes/a, a trap efficiency of 80% and a planning horizon of 15 years, as it was considered unrealistic to add the 50-year sedimentation volume of 600 million $m^3$ to a live storage capacity of 110 million $m^3$.

## 8.7 Dam Type Selection

Due to the large design floods the complete river section must be utilised as a spillway. There is no possibility of a lateral spillway over a saddle or through a neck. Embankment type dams that must not be overtopped are therefore not feasible.

The site also has no V-shape characteristics required for arch type dams.

Concrete gravity dams are therefore considered to be the only type of dam suitable for the site. For a re-regulating dam a buttress type dam could be considered, but this will preclude a later raising if the dam were to be upgraded to a yield dam.

Due to its inherent lower costs a rollcrete dam was chosen for the preliminary design.

The layout of the dam and a typical cross-section are shown in **Figures H.3** and **H.5** in **Appendix J**.

## 8.8 Outlet Works

The layout of the outlet works will depend on the method of operation to be adopted. If the existing canal infrastructure downstream of the Vioolsdrif Weir is to be used, water can be released down the river to the weir. If the head in the dam is to be utilised, a pipeline distribution system starting at the dam needs to be constructed.

The estimated monthly demand figures for a re-regulating dam vary from a minimum of 2.3 $m^3/s$ in June to 11.8 $m^3/s$ in January (see Section 2.3 in the report titled 'Hydrology, Water Quality and Systems Analysis : Volume A – Systems Analysis). Two 2 m diameter pipe stacks are allowed for with 1.8 m diameter inlets at 7 m centres. With a normal operating flow velocity of 4 m/s, each pipe stack can discharge 12.6 $m^3/s$. The water will be discharged through 1.2 m diameter sleeve valves. The intake tower will be equipped with coarse trash racks, fine screens and stop log gates.

The estimated maximum environmental flow requirement (EFR) is 400 $m^3/s$ in February. Whilst it can be expected that the dam would normally overflow during this time, allowance has been made for the installation of two 3.0 m wide by 3.5 m high radial gates to act as bottom outlets. With the water level at the bottom of the 110 million $m^3$ live storage (approx RL 196.7 m) the gates will discharge in the order of 170 $m^3/s$ each. With the water level at the FSL of 211.5 m, the gates will discharge in the order of 200 $m^3/s$ each.

The intake to the bottom outlet will be equipped with coarse trash rack screens, stop log gates and emergency gates. Energy dissipation through a hydraulic jump stilling basin will not be possible as the tailwater level will be too low during the environmental releases. Two super elevated deflector buckets are therefore proposed to direct the flow away from the left bank. The need for a pre-excavated plunge pool will have to be established during the detail design stage.

Details of the outlet works are shown in **Figures H.6** to **H.8** in **Appendix H**.

## 8.9 Flood Diversion Works

### *8.9.1 Stage 1*

It is foreseen that an approximately semi circular rollcrete cofferdam will be built on the left hand side of the river valley to close off 250 m of the river channel. If it is assumed that the remaining 100 m wide river channel will act as a broad crested weir, the cofferdam needs to be approximately 8 m high to pass the diversion flood of 3 000 $m^3/s$.

About twelve culverts of 5 x 5 m will have to be installed in the rollcrete for diversion purposes during Stage 2 (total area 300 $m^2$ x 10 m/s = 3 000 $m^3/s$).

### *8.9.2 Stage 2*

Stage 2 will require rollcrete upstream and downstream cofferdams to link the right flank with the already completed dam. A cofferdam height of 15 m would be required to generate 10 m/s through the culverts. The Stage 1 cofferdam will be demolished.

When the dam is ready for impoundment, the river will be diverted through the outlet works during a period of low flow. The culverts will be concreted up and the Stage 2 cofferdams will be demolished.

The proposed layout of the flood diversion works is shown in **Figure H.4** in **Appendix H**.

## 8.10 Access Roads and Site Establishment

Access to the site is difficult due to the steep valley sides. There is also no space available at the dam site for site establishment.

A large enough area for site establishment was identified on the right bank between 4 and 6 km downstream of the site. The access road will consist of the following components:

- 5 km long upgrading of the existing farm road off Namibia Route 1/1 to accommodate construction traffic.
- 7 km long new road on the river bank with reasonably gentle side slopes.
- 1.5 km long by 8 m diameter tunnel to pass near vertical slopes along the river.
- 5 km long new road on the river bank over flat area past the site establishment area.
- 2.5 km new road along the river bank with relatively steep side slopes (1V:1.8H).

The above proposal had to be discarded as the estimated construction cost of the tunnel alone came to more than R40 million.

For the purposes of the preliminary design, a gravel access road on the left bank was costed (see **Figure H.2** in **Appendix H**). The road will consist of the following components:

- 8.7 km long upgrading of the existing farm road off the N7 to accommodate construction traffic.
- 1.8 km long cutting into the steep hillside (1V:1.2H) along the existing canal to accommodate construction traffic.
- 3.5 km long new road on the river bank over flat area past the site establishment area.
- 3 km long cutting into the steep (1V:1.2H) hillside.
- 3.6 km new road along the river bank with relatively steep side slopes (1V:1.9).

The access road will be prone to frequent flooding unless it can be located above approximately 10 m above the river bed level.

The dam sites upstream of the confluence with the Haib River may be more suitable in this respect as access can be gained from the north, roughly along the Haib River course. An access track that was probably used for prospecting purposes already exists along the river course. Suitable areas for site establishment including quarries exist near the confluence. Due to the very low rainfall in the area, the Haib River is not subject to flooding when the Orange River is in flood. This route should form part of further studies during the detail design stage.

## 8.11 Dam Raising

According to the systems analysis, the projected future downstream demands would require a live storage volume of 1 500 million $m^3$ (see Section 4.6.5 in the report titled 'Hydrology, Water Quality and Systems Analysis : Volume A – Systems Analysis). The 50-year sediment volume was estimated at approx 600 million $m^3$ (see **Section 7.2.3**). The total storage volume would be 2 100 million $m^3$ at a spillway height of 54.6 m. This would require a 29.5 m raising of the re-regulating dam.

The re-regulating dam can be raised by adding rollcrete on the downstream side. In order to allow for such an eventuality the Outlet Works were moved 24 m downstream in the preliminary design. The Intake Tower will be extended vertically whilst adding further intakes to the pipe stacks.

## 8.12 Hydropower Potential

The available flow rate for hydropower generation was taken as the monthly demand figures plus the minimum EFR. In the months of December, February and March the flow rate was capped at 25 $m^3$/s; to allow for a realistic range of flows through the turbines. The average flow rate over a full year was estimated at 15.4 $m^3$/s.

The available head was taken as the difference between the minimum operating level (MOL) and the river bed level. The MOL was defined as the bottom of the 110 million $m^3$ live storage at RL 196.7 m. With the riverbed level at RL 176.4 m the minimum available head is 20.3 m.

The maximum generating capacity is 4.2 MW based on an efficiency factor of 85%. The total annual power generation was estimated at 21.3 GWh based on 340 generating days per year.

It is foreseen that a machine hall will be excavated below the proposed outlet works to house the mechanical/electrical equipment. Two machines with a generating capacity of 2.1 MW each will be installed to allow for flexibility in terms of the required flow rate.

The estimated capital cost of the power station is R30 million, which allows for all civil and mechanical/electrical works up to and including the switchgear at the dam site. No allowance was made for the cost of any distribution lines. The estimated potential income is R3.4 million per annum, based on a selling rate of R0.12 per kWh and a carbon emission reduction subsidy of R0.04 per kWh.

## 8.13 Extent of Inundation

The re-regulating dam will push up to the existing weir at Henkriesmond.

A simplified flow profile calculation was carried out to estimate the extent of the backwater curve. During the 1:100-year flood event (estimated at 12 300 $m^3$/s), the flood level will vary from RL 208 m at the dam site to approximately RL 219 m at Goodhouse. Upstream of Goodhouse, the natural flood levels will occur.

# 9. COST ESTIMATE

## 9.1 Introduction

A cost estimate was done for the construction of a rollcrete re-regulating dam at the Vioolsdrif A site. The dam has a total capacity of 260 million $m^3$ and a full supply level at RL 201.5 m. The total project cost at April 2004 rates is estimated to be R 561 million as detailed in **Appendix H**.

## 9.2 Explanatory Notes

### *9.2.1 Clearing*

Clearing of an area of 10 ha at the dam site has been allowed for.

### *9.2.2 River diversion*

The cost for the river diversion allows for excavation to bedrock, formwork for the upstream and downstream faces of the cofferdams, as well as the culverts and rollcrete.

### *9.2.3 Excavation*

The bulk excavation allows for the excavation of the dam structure with 15% assumed to be rock. The confined excavation allows for the excavation of the outlet works with 80% assumed to be rock.

### *9.2.4 Drilling and grouting*

The quantities for drilling and grouting were calculated in accordance with the guidelines in **Appendix A**.

### *9.2.5 Formwork*

The upstream and downstream faces of the dam were taken as gang formed, whilst the outlet works were assumed to be all intricate formwork.

### *9.2.6 Concrete*

The rollcrete quantity allows for the dam structure including the section at the outlet works. The structural concrete quantity allows for the outlet works and the apron slab below the spillway.

### *9.2.7 Reinforcing*

A reinforcing density of 50 kg per $m^3$ of structural concrete was allowed for taking into account the massive nature of most of the outlet works.

### *9.2.8 Mechanical Items*

The mechanical items were priced in accordance with the layouts shown in **Appendix J** with the engineer's estimate for the Berg River Dam as basis.

### *9.2.9 Fencing*

A nominal allowance was made for fencing at the dam site only.

### *9.2.10 Preliminary Works*

The cost estimate for the access road allows for the full distance from the N7 to the dam site.

The allowances for the provision of electricity and construction water to site were based on figures from the Mohale, Nyaka and Bivane (Paris) Dams and Matsoku Weir.

The allowance for railhead and materials handling was escalated from the ORRS figure.

### *9.2.11 Accommodation*

The allowance for accommodation was based on figures for the Mohale, Nyaka, Bivane (Paris) and Berg River Dams and Matsoku Weir, as well as the fact that the site is situated in a remote area. It is recommended that accommodation at the villages of Vioolsdrift / Noordoewer be considered for establishment of construction accommodation.

#### *9.2.12 VAT*

The Value Added Tax rates of the Republic of South Africa and Namibia differ by 1% and the higher value of 15% (applicable in Namibia) has been used.

#### *9.2.13 Cost of Relocations*

From the 1:50 000's of the dam basin, it appears as if there are approximately 10 dwellings/houses to be relocated.

#### *9.2.14 Cost of Land Acquisition*

The area to be flooded by the 1:100 year floodline was estimated at 4 000 ha. From the 1:50 000's, it appears as if an area of about 200 ha has been developed. The unit cost of the land was based on enquiries to a local farmer in the area.

The cost of compensation for mining and prospecting rights is dependent on whether minerals are actually discovered and a nominal figure has been allowed for.

#### *9.2.15 Allowance for Raising*

The cost estimate includes a 24 m extension of the outlet works for a future raising of the dam. The extension will involve the placing of approximately 10 300 $m^3$ of structural concrete at a total project cost of R12 million.

# 10. ECONOMIC ANALYSIS

## 10.1 Methodology

The various development options proposed for the study were analysed in terms of their cost-benefit ratio or URV. The URV, expressed in R/m$^3$ or c/m$^3$, is the net present value (NPV) of costs, including capital and operational costs, of a development option divided by the net present value of the option benefits. The URV was used to compare the various development options and facilitate the selection of the most cost-effective option.

### *10.1.1 Calculation of URV*

The calculation of the URV for the development options was carried out in an Excel spreadsheet. **Appendix I** shows an example of the relevant sheets of the spreadsheet for a development option (Vioolsdrift Re-regulating Dam). For comparison, the options were analysed for the same commission year and for the same evaluation period. The various components and assumptions of the URV calculation are described below.

The URV was firstly calculated for each option with the same commissioning year to determine the options with the lowest URV relative to other development options. Once these were calculated the options were combined into a sequence of options, forming a scenario in order to provide adequately in the water demands until 2025. (See **Section 10.1.7**)

### *10.1.2 Option Costs*

The costs of the development option over the evaluation period were calculated as follows:

- **Engineering costs:** Pre-engineering costs were taken as 4% of the capital cost and construction costs were taken as 15% of the capital cost.
- **Annual maintenance costs:** The civil component of maintenance cost was taken as 0,25% of the civil capital cost and the mechanical and electrical component of maintenance cost was taken as 4% of the mechanical and electrical capital cost. These figures were taken from Appendix A, Section 3.5, “Guidelines for the Economic Life, and Annual Operational and Maintenance Costs.”

- **Periodic maintenance cost:** The maintenance period was taken as 50% of the option economic life. The option economic life was also taken from Appendix A, Section 3.5, "Guidelines for the Economic Life, and Annual Operational and Maintenance Costs". The economic life period is 50 years for civil works and 30 years for electrical and mechanical. The periodic maintenance cost for civil works was taken as 4% of the civil capital cost and the periodic maintenance cost for electrical and mechanical was taken as 15% of the electrical and mechanical capital cost.
- **Residual value:** If the economic life of the option was greater than the analysis period, the residual value of the option at the end of the analysis period was included in the cost calculation, based on the pro-rata NPV of the option.

### *10.1.3 Option Benefit*

The option benefit is defined as the portion of the option yield, which is used to meet demand. For illustration, the shaded area in **Figure 10-1** shows the benefit of the Vioolsdrif Re-regulating Dam option. **Figure 10-1** shows an existing yield of 14 $Mm^3/a$, a demand curve, and an option yield of 170 $Mm^3/a$. The part of the yield, which exceeds demand, is not considered as a benefit.

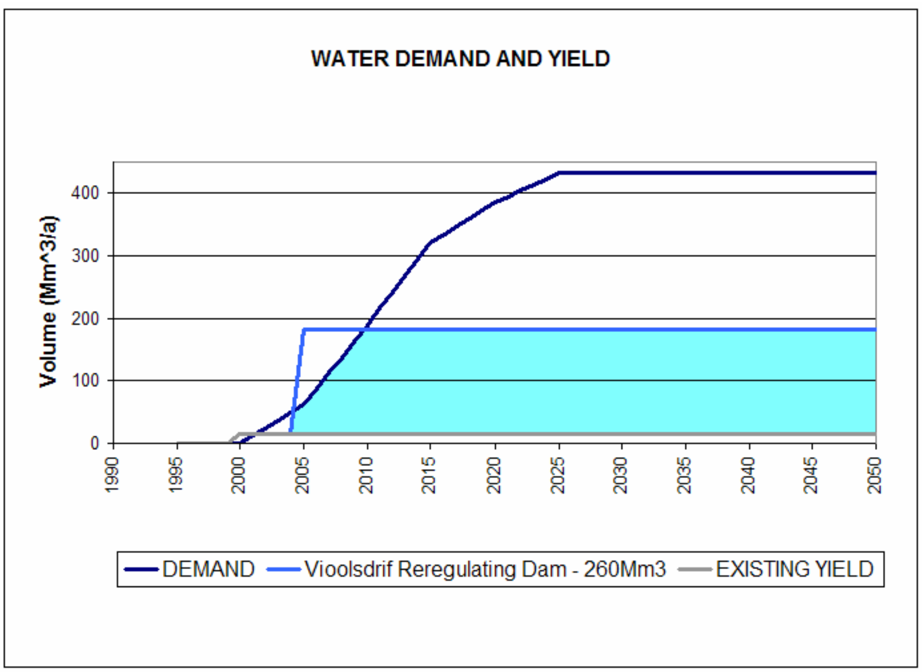


**Figure 10-1: Benefit of Vioolsdrif Re-regulating Dam Option**

#### *10.1.4 Demand Curve*

The demand curve used in the option analysis, shown in **Figure 10-1** and **Figure** 10-2, is the most probable demand growth curve described in other reports, such as the Water Requirements Report and in Chapter 4 of Volume A of the Hydrology Report.

#### *10.1.5 Existing Yield*

An existing yield of 14 $Mm^3/a$ was assumed for the option analysis. This value is the surplus yield at 2005-development level for Reference Scenario 3, described in Chapter 4 of Volume A of the Hydrology Report. The yield of the option being analysed was added on to the existing yield, as shown in **Figure 10-2**.

#### *10.1.6 Discount Rate*

The URV was calculated for low, medium and high discount rate estimates of 6%, 8% and 10%, to test sensitivity and later also tested at a 3% discount rate.

#### *10.1.7 Implementation Date*

All options were analysed with a common date for implementation. The date for implementation was selected as 2005 being the point in time that a further resource should be operational to meet the growth in demand. It means that it was assumed that all capital expenditure required before that date were already done before 2005.

## 10.2 Scenarios

Development scenarios were generated by creating a sequence of options, when each new option was commissioned in the year where the demand exceeded the combined yield of the preceding options. This is illustrated in **Figure 10-2**, which shows the scenario consisting of Vanderkloof Dam lower level storage followed by the raising of Vioolsdrif Re-regulating Dam.

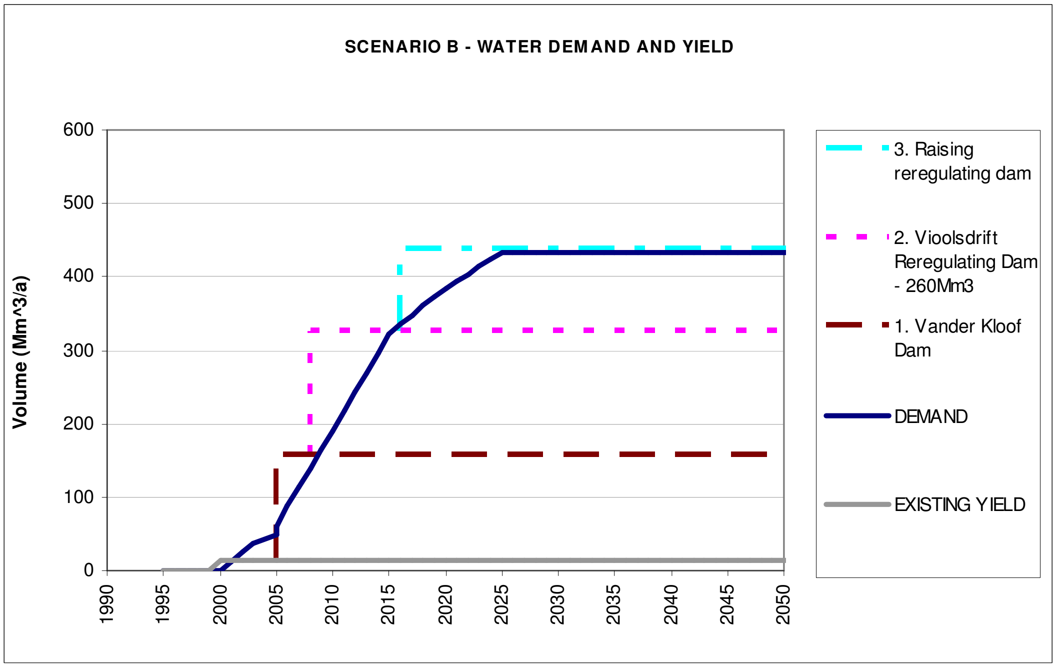


**Figure 10-2: Plot of Yield for a Scenario**

The URV of each scenario was calculated by dividing the total NPV of costs of the options forming the scenario by the total NPV of benefits of the options. The URVs of different scenarios were compared to determine which scenarios were most cost-effective.

The scenarios were compiled by implementing the most cost effective option first followed by the second most cost effective option, considering the practical implementation conditions as well.

## 10.3 Assessment of Pre-screened Dam Development Options

The initial processing of options took place on the basis of direct comparison of costs and other factors as described earlier.

The relation of the most beneficial site between Boegoeberg, Vioolsdrift (and Komsberg) for further analysis, took place in a multi criteria decision workshop. The URVs for these options were calculated and is shown in **Annexure I**.

The capital costs and yields were used as was available at the time. The costing was done at August 2002 prices and URVs calculated at 2003 base year. The results are shown in **Table 10.1**.

## Table 10.1: Assessment of Dam Development Options

| | BOEGOEBERG | | | | VIOOLSDRIF | | | | KOMSBERG |
|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Re-regulating** | **Small Storage** | **Medium Storage** | **Large Storage** | **Re-regulating** | **Small Storage** | **Medium Storage** | **Large Storage** | **Re-regulating** |
| Capacity: Prov. for silt million m³ | 73 | 710 | 710 | 710 | 150 | 600 | 600 | 600 | 160 |
| Capacity: Storage million m³ | 90 | 500 | 1500 | 2000 | 110 | 500 | 1500 | 2400 | 100 |
| Capacity: Total million m³ | 163 | 1210 | 2210 | 2710 | 260 | 1100 | 2100 | 3000 | 260 |
| Spillway height (m) | 19,8 | 35,4 | 42,1 | 44,6 | 25,1 | 44 | 54,6 | 62,6 | 22 |
| Total project cost (R million) | 192 | 872 | 1002 | 1078 | 318 | 691 | 946 | 1181 | 230 |
| Yield million m³ | 62 | 221 | 320 | 357 | 170 | 407 | 494 | 565 | 126 |
| URV (R/m³) | | | | | | | | | |
| 3% Discount rate | 0,17 | 0,39 | 0,28 | 0,26 | 0,11 | 0,14 | 0,17 | 0,21 | 0,11 |
| 6% Discount rate | 0,27 | 0,62 | 0,49 | 0,48 | 0,19 | 0,26 | 0,33 | 0,41 | 0,18 |
| 8% Discount rate | 0,35 | 0,82 | 0,69 | 0,68 | 0,26 | 0,38 | 0,50 | 0,62 | 0,28 |
| 10% Discount rate | 0,44 | 1,06 | 0,95 | 0,94 | 0,34 | 0,52 | 0,71 | 0,88 | 0,31 |

## 10.4 Assessment of Management Options

The management options such as Water Conservation and Demand Management (WC & DM) options were also calculated on a comparable basis with the dam development options. These options are described in the main report but are briefly repeated here for ease of reference. The capital and annual costs of the combined interventions at the Gifkloof to Neusberg area and the Neusberg to border area were used to calculate the URVs as explained earlier. The results were also presented at the Multi-criteria Decision Workshop where it was decided that the two governments will pursue these options further but due to a number of uncertainties about making the actual saved water available to other users, it was not considered to be feasible for further investigation in this study. The results of the (WC & DM) options are shown in **Table 10.2**.

**Table 10.2: Water Conservation and Demand Management Options**

| | Area 1 Gifkloof to Neusberg | Area 2 Neusberg to Border |
|---|---|---|
| Capital investment required | 259 | 122 |
| Annual O&M cost | 14,7 | 8,1 |
| Water saving | 71 | 46 |
| URV 8% | 0,6 | 0,45 |

## 10.5 Vioolsdrift Development Options

After the selection of the Vioolsdrift Dam as the preferred development option the preliminary design costs were determined at an April 2004 base date, as described earlier. The dead storage capacity required for sediment was also reconsidered as described and new costs calculated. URVs were calculated with a base year of 2005.

The calculations are included in **Appendix I 3**, but summarised in **Table 10.3** below. The option of utilising the lower level storage of Vanderkloof Dam is the subject of separate investigations and for this study it was not considered further, but rather to be more appropriate for strategic utilisation as an emergency scheme.

### Table 10.3: Vioolsdrif Dam Development Options

| Parameter | Re-regulating Dam | Re-regulating Dam with Provision for Raising | 600 million $m^3$ Dam | 1300 million $m^3$ Dam | Raising Re-regulating Dam to 600 million $m^3$ Dam | Raising Re-regulating Dam to 1300 million $m^3$ Dam |
|---|---|---|---|---|---|---|
| Capacity: Provision for silt million $m^3$ | 150 | 150 | 210 | 360 | 210 | 360 |
| Capacity: for re-regulating million $m^3$ | 110 | 110 | 110 | 110 | 110 | 110 |
| Capacity: Storage million $m^3$ | 0 | 0 | 280 | 830 | 280 | 830 |
| Capacity: Total million $m^3$ | 260 | 260 | 600 | 1300 | 600 | 1300 |
| Total wall height (m) | 35 | 35 | 45 | 56 | 10 (45) | 21 (56) |
| Total project cost (R million) | 549 | 561 | 722 | 941 | 194 (755) | 411 (972) |
| Total project cost excl. planning design and supervision (R million) | 481 | 493 | 637 | 830 | 173 (666) | 364 (857) |
| Capital cost for civil works (R million) | 458 | 470 | 612 | 802 | 170 (640) | 358 (828) |
| Capital cost for mech works (R million) | 23 | 23 | 25 | 28 | 3 (26) | 6 (29) |
| Construction period (years) | 4 | 4 | 4 | 5 | 2 (6) | 3 (7) |
| Yield million $m^3$ | 170 | 170 | 280 | 418 | 110 (280) | 248 (418) |
| URV (R/ $m^3$) | | | | | | |
| 3% Discount rate | 0.17 | 0.17 | 0.14 | 0.14 | (0.13) | (0.11) |
| 6% Discount rate | 0.29 | 0.29 | 0.26 | 0.28 | (0.22) | (0.19) |
| 8% Discount rate | 0.39 | 0.40 | 0.36 | 0.40 | (0.29) | (0.26) |
| 10% Discount rate | 0.51 | 0.52 | 0.48 | 0.56 | (0.37) | (0.34) |
| | | | | | | |
| Note: Figures in brackets indicate the total applicable after the raising | | | | | | |
| | | | | | | |

# 11. CONCLUSIONS AND RECOMMENDATIONS

## 11.1 Development of Design and Cost Criteria

The study on the Dam Development Options commenced with a review of the 'Guidelines for the preliminary sizing, costing and engineering economic evaluation of planning options' developed during the VAPS for the South African DWAF.

The component sizing criteria were reviewed and modified where deemed necessary. In particular, the sections on flood determination for the various dam types were rewritten due to inconsistencies in the terminology and presentation in the VAPS guidelines. The sections on foundation grouting were rewritten to be consistent between the various dam types. A section on guidelines for estimating social, environmental and administration costs was included.

The cost models were updated by utilising contract prices, with appropriate escalation, for the recently constructed Maguga, Mohale, Inyaka and Bivane (Paris) Dams, as well as the Matsoku Weir.

It is recommended that these adjusted guidelines be accepted by the Client as the new standardised guidelines.

## 11.2 Identification of Dam Sites

The purpose of this sub-task was to mark up all the relevant options identified in the ORRS on the 1:50 000 topographical maps, to identify any new options to the west of the 20° longitude along the common border between South Africa and Namibia and to identify a potential dam site on the Fish River.

In the ORRS, eight possible development options upstream of the common border were identified and evaluated. No new sites were identified in this study. These development options are listed in **Table 3.1.** Furthermore, the potential dam sites along the common border area that were identified in this study, as well as those identified in the ORRS, are listed in **Table 3.2.**

These sites were all considered in the pre-screening process to determine the possible sites to be considered further in the analysis.

A site was also selected at Koubis on the Fish River, immediately upstream of the Ai-Ais Nature Reserve, as being representative of typical sites in the area that could also provide in some needs at the River Mouth. This site provided reservoir characteristics for input into the hydrological model of the LOR. Initial runs of the hydrological model indicated that a dam on the Fish River would not be attractive in the regional context and no further investigations were carried out.

## 11.3 Environmental Considerations and Existing Infrastructure

Before the pre-screening of the development options could be undertaken, background data had to be obtained on the environmental considerations associated with, as well as the existing infrastructure that could be affected by the proposed options. The following pre-screening factors were investigated:

- Reaches of ecological importance and sensitivity.
- Areas of archaeological and historical interest.
- Cultivated land that could be inundated due to dam development.
- Land over which various mining and prospecting licenses had been issued, and for which the licensees would have to be compensated for areas that would be inundated.
- Towns and villages that would be inundated.
- National parks.
- Powerlines across the river that would possibly have to be re-routed.
- Roads and bridges across the river that would possibly have to be re-routed.

### *11.3.1 Ecological Issues*

The following issues of concern were identified:

- The natural distribution of the median monthly flows in the LOR, which have already been significantly altered by the Gariep and Vanderkloof Dams, may be distorted even more.
- A new impoundment will have physico-chemical effects such as stratification and riverbed degradation.
- It will also impact on the riverine biota, such as vegetation, freshwater invertebrates and freshwater fish species.
- Unique river reaches such as inland deltas will be affected.

### *11.3.2 Areas of Archaeological and Historical Interest*

The following conclusions were made on the above topic:

- Extrapolating from what is known from localities to the east and west of the study area, it could reasonably be predicted that any potential dam site within the study area will have heritage impacts.
- The Richtersveld is archaeologically rich and inundation of the river valley will have an impact in the immediate vicinity of the river.
- A preliminary field assessment will be necessary before any idea of the kinds of impacts that may be involved, can be gained.
- Some detailed archival research may also be necessary to identify places of conflict as well as help establish the significance of any sites found.

### *11.3.3 Cultivated Land*

Presently cultivated areas along the common border, as well as potentially irrigable areas along both the South African and Namibian sides of the river were recorded during the course of the investigation for the purpose of determining possible impacts, existing and future water requirements. Also for WC & DM opportunities.

### *11.3.4 Mining and Prospecting Licenses*

Mining and prospecting licenses have been issued over much of the reach of the common border and mining for diamonds, pegmatites, flourspar and tungsten had taken place in the area. It is not possible to quantify the cost of compensation for the loss of prospecting and mining licenses, or differentiate between the licenses. The cost of compensation has therefore been assumed to be equal for all sites.

#### *11.3.5 Roads and Bridges*

Three bridges cross the Orange River along the common border, namely at Oranjemund/Alexander Bay, Vioolsdrif/Noordoewer and Onseepkans. The extent to which these bridges and their approaches will be inundated by any dams constructed on the river will depend on the full supply levels of the dams.

#### *11.3.6 Towns and Villages*

Two towns, namely Goodhouse and Onseepkans, could be partly or wholly inundated by water impounded by new dams constructed at the Vioolsdrif and Kambreek sites. Prieska may also be affected by a larger dam at Boegoeberg.

#### *11.3.7 National Parks*

The Ai-Ais Nature Reserve in Namibia and the Richtersveld Nature Reserve and Augrabies Falls National Park in South Africa border on the Orange River and may therefore be partly inundated by dam construction by some of the identified sites.

#### *11.3.8 Powerlines*

Four powerlines that cross the Orange River along the common border have been identified, namely at Oranjemund, Rosh Pinah, Noordoewer and on the Farm Kabis.

### 11.4 Pre-screening of Development Options

#### *11.4.1 Options Upstream of the Common Border*

The ORRS concluded that most of the initial development options considered in the Orange River Basin could be eliminated from further consideration on financial, social, engineering or environmental grounds. Only a small number of options remained as possible future developments, however, it was not possible to make firm recommendations at that stage. In all of the remaining options, it was considered necessary to create some form of operational storage along the Orange River at either Vioolsdrif or Boegoeberg. Both options had similar URVs and it was not possible to eliminate either of them during the Pre-feasibility Phase of the ORRS.

In the LORMS, no reason could be found to differ from the conclusion of the ORRS that the most feasible option for the construction of a new dam upstream of the common border is the New Boegoeberg Dam.

### *11.4.2 Options along the Common Border*

A preliminary pre-screening was done on the dam sites that were identified earlier, with a view of eliminating those options that were clearly flawed from engineering, social or environmental considerations. It was concluded that the options, namely Vioolsdrif A (as representative of the four sites), Yas and Komsberg were to be subjected to further cost analysis and evaluation against the pre-screening criteria. The comparison between the pre-screening cost and the reservoir capacities is shown in **Figure 11-1** as requested.

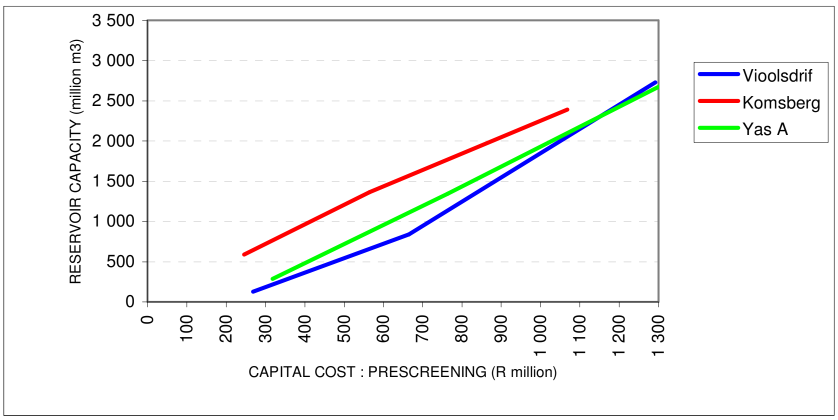


**Figure 11-1: Capital Cost (Comparative) of Dam Construction versus Reservoir Capacity**

The details of the evaluation against the pre-screening criteria are shown in **Table 5.4**, but the salient points are discussed below.

### *11.4.3 Discussion of Pre-screening Analysis*

#### 11.4.3.1 Vioolsdrif A

The dam site is situated close to existing infrastructure, but access to the site will be difficult due to the steep valley sides. The dam will inundate areas over, which mining and prospecting licenses have been issued, over most of the distance that the impounded water pushes up the river.

11.4.3.2 Yas

This dam site is situated approximately 54 km downstream of the border at 20° longitude. As in the case of the Komsberg site, much of the water stored by the dam will be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure, or powerlines. A dam at this site would have a similar cost to dams at the Vioolsdrif sites.

11.4.3.3 Komsberg

This dam site is situated approximately 7 km downstream of the border at 20° longitude. Most of the water stored by the dam will therefore be on the South African side of the border and the dam will inundate parts of the Augrabies Falls National Park, which is situated along the northern side of the river. The dam would not inundate much irrigable land, areas of mining and prospecting licenses, towns or villages, road infrastructure, or powerlines.

Based on the 1:50 000 mapping, this site was found to be the most economical site along the common border for the construction of a dam for the range of reservoir capacities under consideration. However, the extent of the inundation of the Augrabies Falls National Park remained of concern.

## 11.5 Conclusions

Based on the pre-screening the following conclusions were made:

- The Yas dam site does not offer any significant cost benefits over the Vioolsdrif site and will inundate parts of the Augrabies Falls National Park. It was therefore excluded from further analysis.
- From a capital cost point of view (as defined in this section of the report), the Komsberg site is more cost-effective than the Vioolsdrif site for the construction of either a smaller re-regulating dam or a larger dam to improve the yield of the system. The allowable inundation of the Augrabies Falls National Park, however, still had to be determined.

The net result of the pre-screening was that both the Viooldrif A and the Komsberg Dam sites were considered in a multi criteria Decision-making Workshop.

## 11.6 Assessment of Pre-screened Development Options

In the pre-screening process the number of dam sites that could possibly be carried forward to the preliminary design stage was reduced to the following sites:

Upstream of 20$^o$ longitude (i.e., upstream of the common border):

- New Boegoeberg Dam

Downstream of 20$^o$ longitude (i.e., along the common border):

- Vioolsdrif Dam
- Komsberg Dam

These three possible options were investigated in order to make more accurate cost estimates, determine yields and assess benefits and impacts. The options were then evaluated at a multi-criteria Decision-making Workshop by a team consisting of the Client, selected stakeholders and the Consultant.

Prior to the workshop, the following activities were carried out on the three dams:

- A yield analysis was carried out in order to determine the required storage capacities for specified yields.
- A sedimentation analysis was carried out on the New Boegoeberg and Vioolsdrif sites in order to estimate the sedimentation volumes.
- A financial analysis was carried out in order to determine the unit reference values of dams of various storage capacities.

The pertinent data for the New Boegoeberg, Vioolsdrif and Komsberg Dam sites is summarised in **Table 11.1**.

**Table 11.1: Pertinent Values for the Preferred Sites for Re-regulating Dams**

| | New Boegoeberg | Vioolsdrif | Komsberg |
|---|---|---|---|
| Proposed dam size (million $m^3$) | 163 | 260 | 260 |
| Unit reference value (@ 8%) (R/$m^3$) | 0,35 | 0,26 | 0,24 |
| Saving in operational losses (million $m^3$/a) | 62 | 170 | 126 |

At the workshop, it was decided that the Vioolsdrif and Komsberg Dam sites were preferred to the New Boegoeberg Dam site for the following reasons:

- Significantly lower unit reference values; and
- Significantly larger saving in operational losses.

Due to the fact that dams for all heights under consideration at the Komsberg site would inundate parts of the Augrabies Falls National Park, it was decided that the Komsberg site should not be considered unless there were significant cost advantages. The cost estimates of the Vioolsdrif and New Boegoeberg Dam sites had been done on 1:10 000 mapping with 5 m contours, whilst that of the Komsberg Dam site was done on 1:50 000 mapping with 20 m contours. It was therefore decided that 1:10 000 mapping should also be prepared for the Komsberg site. Based on this mapping, the quantities for the Komsberg Dam site were re-calculated. The URV for a dam with a capacity of 260 million $m^3$ increased to R0.28/$m^3$.

The river bed levels downstream of the Augrabies Falls were also checked by using the DEMs of the area. The river bed level at the Komsberg Dam site is at approximately RL 430.8 m. Above a FSL of approximately RL 432 m, water will start pushing up into the Augrabies Falls National Park, and the rapids downstream of the Falls will start to be inundated at levels above RL 450 m. The FSL for the proposed re-regulating dam will be at approximately RL 446 m.

After the workshop, field visits were made to the Vioolsdrif and Komsberg areas in order to carry out a vegetation study and ecological and archaeological assessments.

The improved costing, the results of the vegetation and archaeological studies, the ecological assessment, as well as other factors that needed to be considered in assessing the options were presented to the Client.

A summary of the above assessments is presented in **Table 11.2**.

**Table 11.2: Summary of Assessment of Vioolsdrif and Komsberg Options**

| Dam Sites | Vioolsdrif | Komsberg |
|---|---|---|
| **Issues** | | |
| Potentially serious implications of any raising of the dam in future | None | Inundation of the rapids downstream of the Augrabies Falls. |
| Impact on Augrabies Falls and National Park | None | Dam basin inside the Park and potential sediment and back water effects in rapids |
| Saving in operational losses (million $m^3$/a) | 170 | 126 |
| Ecological | Would have the most impact relative to the other options. | Would have a lower impact than the Vioolsdrif Dam option. |
| Archaeological | Would have the greater impact on archaeological remains. | Would have a lesser impact on archaeological remains than Vioolsdrif. |
| Vegetation | Would overall affect a less developed stretch of riparian landscapes and habitats. | Would affect large stretches of relatively pristine riparian woodlands, though interrupted by agricultural developments. |
| Unit reference values (R/$m^3$) | 0.26 | 0.28 |

On the basis of these factors, it was decided that the development of a re-regulating dam at the Vioolsdrif Dam site was preferred to the Komsberg Dam site.

## 11.7 Preliminary Designs and Cost Estimates

### *11.7.1 Dam Site*

The preliminary design was based on the Vioolsdrif A Dam site due to the smaller cross-sectional area than the other three sites and to facilitate comparison with the ORRS work.

### *11.7.2 Available Mapping*

All the work in the ORRS at the Vioolsdrif Dam sites was based on the 1:50 000 topo-cadastral maps of the area. The 1:50 000 mapping was retained to compile the storage capacity curve for the site, but survey plans at a scale of 1:10 000 with 5 m contours were prepared from aerial photography for the dam site.

#### 11.7.3 Flood Determination

In terms of the Guidelines for Sizing of Mass Concrete Dams, the flood magnitudes were based on the RMF concept. The SED was calculated to be 26 300 $m^3/s$ and the RDD 14 250 $m^3/s$.

The diversion flood for a concrete dam is based on the 1:10-year recurrence Interval (RI) flood, which was estimated to be 3 000 $m^3/s$.

For the preliminary design a total freeboard of 10 m was used.

#### 11.7.4 Spillway Design

Due to the high flood magnitudes that need to be passed over the dam, the complete base width of the valley of 375 m will be used as spillway.

#### 11.7.5 Dam Size

The preliminary design was done for a (re-regulating) dam with the following parameters:

| | |
|---|---|
| • Total storage capacity | 260 million $m^3$ |
| • Allowance for sedimentation | 150 million $m^3$ |
| • Live storage capacity | 110 million $m^3$ |
| • Wall height to NOC | 35.1 m |
| • Wall height to FSL (i.e. spillway height) | 25.1 m |
| • River bed level | RL 176.4 m (approximately) |
| • FSL | RL 201.5 m |
| • NOC | RL 211.5 m |
| • Total crest length | 485 m |

#### 11.7.6 Dam Type Selection

Due to the large design floods, the complete river section must be utilised as a spillway. A concrete gravity dam was therefore considered to be the only type of dam suitable for the site. Due to its inherent lower costs, a rollcrete dam was chosen for the preliminary design.

### *11.7.7 Outlet Works*

The estimated monthly demand figures for a re-regulating dam vary from a minimum of 2.3 $m^3$/s in June to 11.8 $m^3$/s in January. Two 2 m diameter pipe stacks are allowed for with 1.8 m diameter inlets at 7 m centres. With a normal operating flow velocity of 4 m/s each pipe stack can discharge 12.6 $m^3$/s. The water will be discharged through 1.2 m diameter sleeve valves.

The estimated maximum environmental flow requirement is 400 $m^3$/s in February. Whilst it can be expected that the dam would normally overflow during this time, allowance has been made for the installation of two 3.0 m wide by 3.5 m high radial gates to act as bottom outlets

### *11.7.8 Flood Diversion Works*

The first stage of the river diversion will consist of an approximately semi circular 8 m high rollcrete cofferdam that will be built on the left hand side of the river valley to close off 250 m of the river channel. Culverts will be installed in the rollcrete for diversion purposes during the second stage.

The second stage will require 15 m high rollcrete upstream and downstream cofferdams to link the right flank with the already completed dam.

### *11.7.9 Access Roads and Site Establishment*

Access to the site is difficult due to the steep valley sides. There is also no space available at the dam site for site establishment. For the purposes of the preliminary design a gravel access road on the left bank was costed. The access road will be prone to frequent flooding unless it can be located above approximately 10 m above the river bed level.

### *11.7.10 Dam Raising*

According to the systems analysis, the projected future downstream demands may require a live storage volume of 1 500 million $m^3$. The 50-year sediment volume was estimated at approx 600 million $m^3$. The total storage volume would be 2 100 million $m^3$ at a spillway height of 54.6 m. This would require a 29.5 m raising of the re-regulating dam.

The re-regulating dam can be raised by adding rollcrete on the downstream side. In order to allow for such an eventuality the Outlet Works were moved 24 m downstream in the preliminary design. The Intake Tower will be extended vertically whilst adding further intakes to the pipe stacks.

*11.7.11 Hydropower Potential*

The available flow rate for hydropower generation was taken as the monthly demand figures plus the minimum EFR. The average flow rate over a full year was estimated at 15.4 $m^3/s$. The minimum available head is 20.3 m.

The maximum generating capacity is 4.2 MW. The total annual power generation was estimated at 21.3 GWh.

The estimated capital cost of the power station is R30 million, which allows for all civil and mechanical/electrical works up to and including the switchgear at the dam site. No allowance was made for the cost of any distribution lines. The estimated potential income is R3.4 million per annum, based on a selling rate of R0.12 per kWh and a carbon emission reduction subsidy of R0.04 per kWh.

## 11.8 Cost Estimate

The total project cost for a rollcrete re-regulating dam at the Vioolsdrif A site at April 2004 rates is estimated to be R 561 million. The costs for the raising of the dam to 600 million $m^3$ and 1300 million $m^3$ capacity was also calculated at the same basis to enable the economic analysis of further options.

## 11.9 Economic Analysis

The Boegoeberg, Vioolsdrif and Komsberg sites were compared on an engineering economic basis. It firstly proved that the Vioolsdrif site is more beneficial than the Boegoeberg site for the full spectrum of capacities investigated. Initially, a re-regulating dam at Komsberg seemed more beneficial than at Vioolsdrif, but after more detailed mapping was obtained, Vioolsdrif proved to be the more economic site for the re-regulating dam.

The calculation of the URV for the different Vijoolsdrift options, based on the April 2004 cost estimates and 2005 URV base date, were performed and the results are indicated in **Table 10.3**. The analysis proved that the provision for future raising of the re-regulating dam is not that costly and it is recommended that it should be designed accordingly. The analysis also proved that it is economically more feasible to raise the re-regulating dam than to construct the full capacity dam at once. The optimum phasing was not determined.

The analysis proved that the re-regulating dam only will not make adequate additional yield available to serve the full demand until 2025. Additional storage on the system is required. This additional storage can be created at Vioolsdrift or elsewhere outside of the study area. The investigation of these options is outside the scope of this study.

# 12. REFERENCES


| | |
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# APPENDICES

**A** Guidelines for the Preliminary Sizing, Costing and Engineering Economic Evaluation of Planning Options

**B** Locality Map

**C** Location of Potential Dam Sites (1:250 000 and 1:500 000 Maps)

- C1 to C8: Orange River Mouth to 20$^{o}$ longitude (including pre-screening factors)
- C9 to C12: 20$^{o}$ Longitude to Vanderkloof Dam
- C13: Fish River
- C14: Correspondence with South African Department of Minerals and Energy

**D** Layouts of Potential Dam Sites (1:20 000 maps)

**E** Cross-sections of Potential Dam Sites

**F** Longitudinal Profile of the Orange River

**G** Report on the Sedimentation Analysis

**H** Preliminary Design of Vioolsdrif Re-regulating Dam

**I** Unit Reference Value Calculations

- I1: Pre-screened Options and Scenarios
- I2: Management Options
- I3: Vioolsdrift Development Options

# APPENDIX A

## Guidelines for the Preliminary Sizing, Costing and Engineering Economic Evaluation of Planning Options

# APPENDIX B

## Locality Map

# APPENDIX C

## Location of Potential Dam Sites
## (1:250 000 and 1:500 000 maps)

C1 to C8: Orange River Mouth to 20º Longitude (including Pre-screening Factors)

C9 to C12: 20º Longitude to Vanderkloof Dam

C13: Fish River

**APPENDIX C14**

**Correspondence with South African Department of Minerals and Energy**

# APPENDIX D

## Layouts of Potential Dam Sites
## (1:20 000 maps)

# APPENDIX E

## Cross-sections of Potential Dam Sites

# APPENDIX F

## Longitudinal Profile of the Orange River

# APPENDIX G

## Report on Sedimentation Analysis

**APPENDIX H**

**Preliminary Design of Vioolsdrif Re-regulating Dam**

**APPENDIX I**

**Unit Reference Value Calculations**

I1: Pre-screened Options and Scenarios

I2: Management Options

I3: Vioolsdrif Development Options

**Photographs**

**Figures**

**Cost estimate**

| No | PAY REF | DESCRIPTION | UNIT | RATE 01-Apr-04 Rand | QUANTITY | AMOUNT Rand |
|---|---|---|---|---|---|---|
| 1 | 5.1 | **Clearing** | | | | |
| | 5.1.1 | (a) sparse | ha | 4 000 | 7 | 28 000 |
| | 5.1.2 | (b) bush | ha | 8 000 | 2 | 16 000 |
| | 5.1.3 | (c) trees | ha | 16 000 | 1 | 16 000 |
| 2 | 5.2 | **River diversion** | Sum | | | 42 000 000 |
| 3 | 5.3 | **Excavation** | | | | |
| | | (a) Bulk | | | | |
| | 5.3.1 | (i) all materials | m3 | 23 | 131960 | 3 035 080 |
| | 5.3.3 | (ii) extra over for rock | m3 | 42 | 23300 | 978 600 |
| | | (b) Confined | | | | |
| | 5.3.2 | (i) all materials | m3 | 34 | 4150 | 141 100 |
| | 5.3.3 | (ii) extra over for rock | m3 | 57 | 16600 | 946 200 |
| | 5.3.4 | (c) Final foundation preparation | m2 | 37 | 23700 | 876 900 |
| 4 | 5.4 | **Drilling & Grouting** | | | | |
| | | (a) Curtain grouting | m drill | 370 | 4715 | 1 744 550 |
| | | (b) Consolidation grouting | m drill | 370 | 12300 | 4 551 000 |
| 5 | 5.6 | **Formwork** | | | | |
| | 5.6.1 | (a) Gang formed | m2 | 100 | 23030 | 2 303 000 |
| | 5.6.2 | (b) Intricate | m2 | 210 | 13200 | 2 772 000 |
| 6 | 5.7 | **Concrete** | | | | |
| | 5.7.3 | (a) Rollcrete | m3 | 310 | 217050 | 67 285 500 |
| | 5.7.4 | (b) Facecrete including waterstop | m3 | 420 | 19020 | 7 988 400 |
| | 5.7.2 | (c) Structural | m3 | 470 | 37820 | 17 775 400 |
| 7 | 5.8 | **Reinforcing** | t | 5 200 | 1890 | 9 828 000 |
| 8 | 5.9 | **Mechanical Items** | | | | |
| | 5.9.1 | (a) Pipes, valves & gates | Sum | | | 14 500 000 |
| | 5.9.2 | (b) Cranes & hoists | Sum | | | 1 100 000 |
| | 5.9.3 | (c) Structural steelwork | t | 16 000 | 10 | 160 000 |
| 9 | 5.10 | **Fencing** | km | 16 000 | 1 | 16 000 |
| | | **SUB-TOTAL** | | | | **178 061 730** |

| No | PAY REF | DESCRIPTION | UNIT | RATE 01-Apr-04 RAND | QUANTITY | AMOUNT |
|---|---|---|---|---|---|---|
| 10 | 5.11 | **Landscaping** (% of 1-9) | % | 5 | | 8 903 087 |
| 11 | 5.12 | **Miscellaneous** (% of 1-9) | % | 15 | | 26 709 260 |
| | | **SUB TOTAL A** | | | | **213 674 076** |
| 12 | 5.13 | **Preliminary & General** (% of sub-total A) | | | | |
| | | Fixed charges | % | 15 | | 32 051 111 |
| | | Time-related charges (3 years) | % | 25 | | 53 418 519 |
| 13 | 5.14 | **Preliminary works** | | | | |
| | 5.14.1 | (a) Access road | km | 2 000 000 | 20.6 | 41 200 000 |
| | 5.14.2 | (b) Electrical supply to site | Sum | | | 4 000 000 |
| | 5.14.3 | (c) Construction water to site | Sum | | | 2 000 000 |
| | 5.14.4 | (d) Railhead & materials handling | Sum | | | 4 000 000 |
| 14 | 5.15 | **Accommodation** | Sum | | | 10 000 000 |
| | | **SUB TOTAL B** | | | | **360 343 706** |
| 15 | 5.16 | **Contingencies** (% of sub total B) | % | 10 | | 36 034 371 |
| | | **SUB TOTAL C** | | | | **396 378 077** |
| 16 | 5.17 | **Planning design & supervision** (% of sub total C) | % | 15 | | 59 456 712 |
| | | **SUB TOTAL D** | | | | **455 834 789** |
| 17 | 5.18 | **VAT** (% of sub total D for Namibia) | % | 15 | | 68 375 218 |
| | | **NETT PROJECT COST** | | | | **524 210 007** |
| 18 | 5.19 | **Cost of relocations** | Sum | | | 2 000 000 |
| 19 | 5.20 | **Cost of land acquisition** | Sum | | | |
| | | (a) Undeveloped | ha | 4 000 | 3 800 | 15 200 000 |
| | | (b) Developed | ha | 50 000 | 200 | 10 000 000 |
| | | (c) Compensation for mining and prospecting rights | Sum | | | 10 000 000 |
| | | **TOTAL PROJECT COST** | | | | **561 410 007** |