APPENDIX C

DISCUSSION DOCUMENT ON

THE DETERMINATION AND MANAGEMENT OF THE WATER RELEASES FROM THE MOKOLO DAM AND THE DAMS IN THE CROCODILE RIVER (WEST) AND ITS TRIBUTARIES TO SUPPLY THE MCWAP

MOKOLO AND CROCODILE (WEST) WATER AUGMENTATION PROJECT (MCWAP) FEASIBILITY STUDY

REPORT 10: REQUIREMENTS FOR THE SUSTAINABLE DELIVERY OF WATER

Project No. WP9528

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1. INTRODUCTION

1.1 Background

There are a number of planned and anticipated consequential developments in the Lephalale area and up to Steenbokpan in the west that are associated with the rich coal reserves in the Waterberg coal field. These developments will require additional water supplies from both the Mokolo River and the Crocodile River (West), which are shown in Figure 1-1. Both these rivers are part of the Limpopo Watercourse, which is shared by South Africa and its neighbouring states of Botswana, Mozambique and Zimbabwe.

The Mokolo (Mogol) River catchment is part of the Limpopo Water Management Area (WMA). The Mokolo River originates close to Modimolle (Nylstroom) and then drains to the north into the Limpopo River. The Mokolo Dam (formerly known as the Hans Strijdom Dam) is the only source of surplus water that is readily available to augment the water supplies to the Lephalale area at an early stage, but the surplus water is far too little to supply the eventual water requirements in this area.

The Crocodile River (West) catchment is part of the Crocodile River (West) / Marico WMA. The Crocodile River (West) originates in the northern suburbs of Johannesburg and drains to the north-west into the Limpopo River. The Hartebeespoort Dam (in the catchment area of the Roodekopjes Dam) and the Klipvoor, Roodekopjes and Vaalkop Dams are all significant dams upstream of the site at Vlieëpoort on the Crocodile River (West) from which water will be abstracted to augment the supplies to the Lephalale area. The natural runoff from the catchments of these dams is already fully utilised to supply existing users and use is already being made of some of the effluent flows from the Johannesburg area to augment the supplies to the existing users.

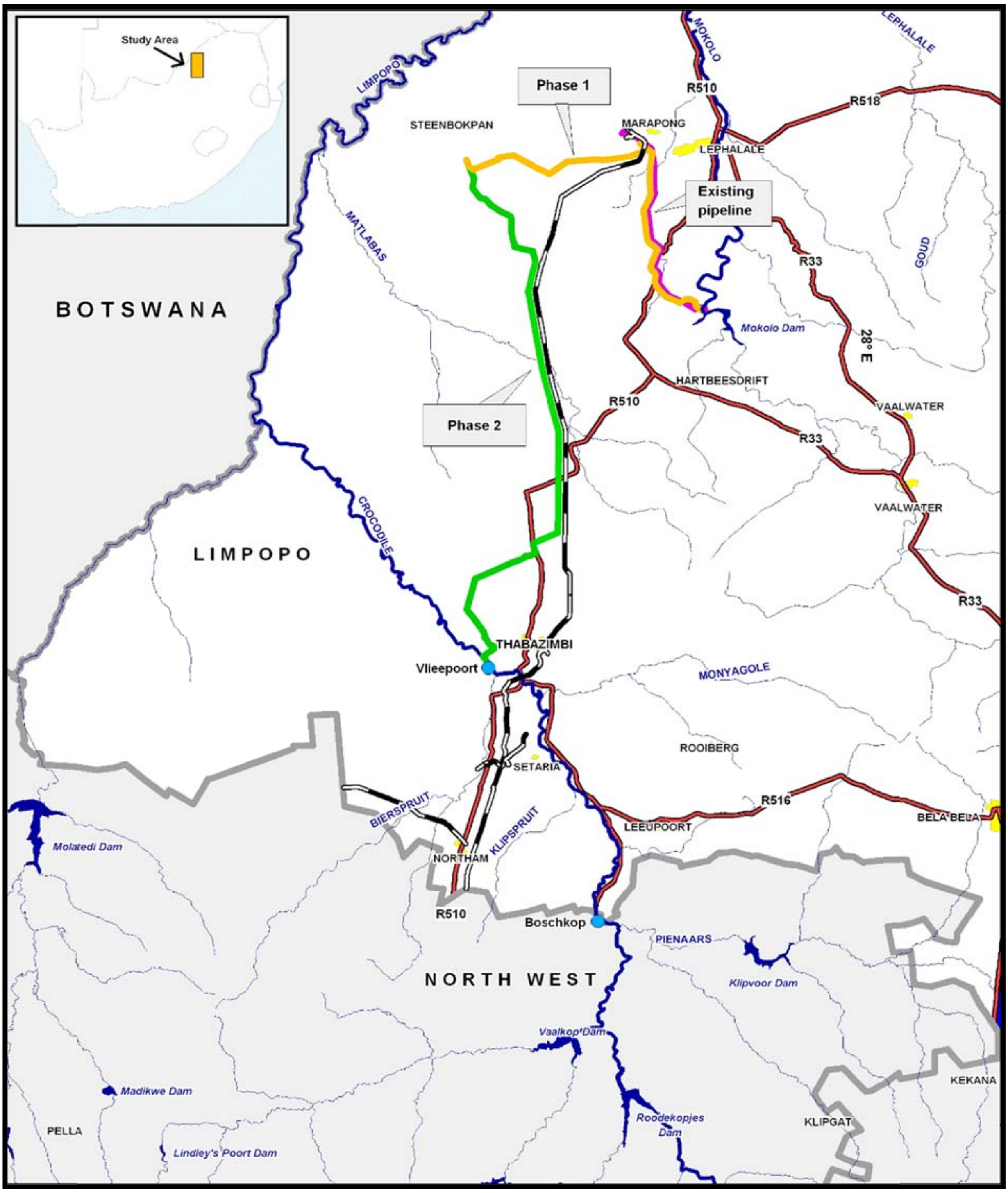

Figure 1-1: Overall Layout of MCWAP

The MCWAP will be developed in the following two phases:

- Phase 1: Augment the water supply directly from Mokolo Dam to supply in the growing water requirements in the area between Lephalale and Steenbokpan. During this period the firm yield of the dam will be exceeded for a short period until the Phase 2 transfer pipeline from the Crocodile River (West) can be implemented; and

- Phase 2: Further augment the water supply by transferring water from the Crocodile River (West) to the area between Lephalale and Steenbokpan.

It will be necessary to have dedicated authorities to manage the water allocated to the MCWAP by DWA, to manage the use of the allocated water by the users supplied from the MCWAP and to manage, operate and maintain the MCWAP. These institutional arrangements will be determined by TCTA. Possible institutional arrangements are discussed in Chapter 7, Section 4 of Report 10. Essentially these consist of the MCWAP Authority that is supported by the MCWAP Scheme Management Authority (MCWAP SMA), the Mokolo River Management Authority (MR RMA) and the Crocodile (West) River Management Authority (CRW RMA).

1.2 Purpose of the Report

The purpose of this report is to describe, in broad outline, the issues that need to be considered in each of the Mokolo and Crocodile River (West) catchments and that will affect the water available to the MCWAP Authority (and finally to the bulk users in the Lephalale – Steenbokpan industrial development area), including:

- Tasks to be performed by the responsible authority, partly in support of DWA (discussed in other parts of this Report);
- The decision support systems that will be required to perform the function;
- The expected water abstraction and river flow measurement and recording infrastructure that will be required;
- The additional river flow measurement and recording infrastructure required, data processing, display and archiving, reconciliation of dam releases, river flows, water use, river losses, river outflows and diffuse and tributary accruals, and
- Communication with affected parties and user representatives.

This report does not address the issues and management of water use and river flows in the catchments upstream of the Mokolo, Klipvoor, Roodekopjes and Vaalkop Dams nor downstream of the Mokolo Dam or downstream of Vlieëpoort.

2. WATER USERS

2.1 Mokolo River Catchment

The main water users from the Mokolo River catchment are the town of Vaalwater, the irrigators upstream of the Mokolo Dam, the irrigators downstream of the dam that receive water released from the dam into the Mokolo River, and the Lephalale Municipality, Exxaro and Eskom and the MCWAP (in future) that abstract water directly from the dam.

2.2 Crocodile River (West) Catchment

The main water users from the portion of the Crocodile River (West) catchment downstream of the Klipvoor, Roodekopjes and Vaalkop Dams are the existing users that comprise:

- The irrigators downstream of the three dams represented by the Crocodile River Irrigation Board (upstream of Vlieëpoort) and the Makoppa Farmers (downstream of Vlieëpoort);
- the platinum mines and associated settlements to the west of the Crocodile River (West);
- a number of rural towns and villages north and east of the Pilanesberg and also in the catchment of the Tolwane River (tributary of the lower Pienaars River) between the Klipvoor and Roodekopjes Dams;
- the users supplied from the small Zandriviersdrift and Bierspruit Dams on the Sandrivier and Bierspruit respectively, and
- Thabazimbi Local Municipality and the MCWAP (in future).

Downstream of the Klipvoor, Roodekopjes and Vaalkop Dams the Crocodile River (West) is characterised by a very flat slope and a number of prominent meanders in flat alluvial plains. Preliminary desktop investigations indicate that these alluvial plains are underlain by relatively coarse lenticular alluvial deposits that are hydraulically connected to the Crocodile River (West) and that have created sedimentary aquifers that are recharged by rainfall and from the river. These aquifers are a major source of water for the irrigators who have drilled into them and are abstracting water from the boreholes on the basis that it was groundwater, whereas the water is mostly derived from the river. Water abstracted from boreholes inside the so-called “red-line” is considered to be river water and should be treated as such for the purposes of the River Management Plan.

3. DECISION SUPPORT SYSTEMS

Decision support systems will be required by DWA and the RMA to manage water supplies, releases, river flows and abstractions. Water resource allocation models should be utilised to do water allocations and curtailments to the various users and river flow management models should be utilised by the RMA to manage releases, river flows and abstractions.

3.1 River Flow Management Models

No decision support models are envisaged for the MR RMA. Only one decision making case is anticipated when variations from the normal seasonal abstraction patterns occurs whenever the MCWAP SMA experiences a supply interruption from the Crocodile River (West). In such a case the MR RMA must abstract additional water from the Mokolo Dam, using the unutilised abstraction capacity, until the interruption has been rectified in order to minimise the rate of abstraction from the Terminal Reservoirs. After the supply interruption from the Crocodile River (West) has been rectified the rate of abstraction from the dam will be reduced for a while to ensure that the annual entitlement of the MCWAP SMA from the dam is not exceeded. Likewise, whenever there is a supply interruption from the Mokolo Dam additional water must be supplied from the Crocodile River (West) until the interruption has been rectified. The rate of abstraction from the dam will then be increased for a while to ensure that the annual entitlement of the MCWAP SMA is fully utilised.

The following two river flow management decision support models are envisaged for the CRW RMA to enable it to estimate the daily flow releases required from the Roodekopjes Dam (and possibly also the Klipvoor and Vaalkop Dams) in real present and future time:

- A steady flow water release model that administers water requests and directly estimates (designs) the water release hydrographs from the dam(s), taking account of variable diffuse and tributary downstream accruals, diffuse losses and outflows, abstractions and river flow lag times; and
- An unsteady flow simulation model to confirm the output from the steady flow water release model and with which it can be calibrated from time to time.

3.1.1 Steady Flow Water Release Model

The primary objective of this model is to determine the timing and magnitude of water releases that are required from the above dam(s) to supply downstream water requirements when these exceed the available downstream flows in the river system. The model should be an operational management tool that employs simplified techniques to ensure that the water release design process can be put into practice on a day-to-day basis. Releases should however, be done in an efficient manner without undue wastage.

Typically the model that is envisaged will be used to determine a preliminary water release hydrograph that is based on a lagged accumulation of system water requirements that is then adapted by the operator. River reaches are defined according to representative cross-sections, bed slopes and channel roughness. The model will generally require periodic calibration (at least seasonally) to account for natural modifications of river channel characteristics. The technology and support is readily available locally.

The model must be real-time enabled to allow for the import of real time data from a data acquisition system and would be the primary river flow management decision support model for day-to-day use. It is a hydraulic river flow model operated in real present and future time. The model is used to optimise the use of water by reducing unnecessary water releases from the Roodekopjes Dam (and possibly also the Klipvoor and Vaalkop Dams). The real time quantities and timing of flow releases to be made from the dam(s) are determined on the basis that the consumptive water requirements (including MCWAP requirements), the Ecological Reserve(s) and the flows required into the Limpopo River from the Crocodile River (West) are met at the appropriate times.

A big advantage of the steady flow water release model is its ease of use and the fact that the degree of operator input is low, while still producing high-confidence estimates of release requirements. The model is also intended to be a tool to illustrate river management issues at water user forums. The model must therefore be able to perform its operations quickly, with a user friendly output.

The routine river flow management procedure generally requires the following three sequential steps:

- Data input;
- Water release hydrograph estimation; and
- Adjustment of the water release hydrograph by the model for implementation.

After the model has been calibrated its operation will become a routine bi-annual task to be performed regularly. An experienced civil engineering technician will normally be sufficiently qualified to use the model.

The river system that must be managed is not unduly complex, and does not include many structures that modify the flow regime. Typically a standard software package would be acquired that is adapted, configured and populated with data relevant to the Crocodile River (West). Such models are currently in use at many irrigation schemes in South Africa and also in certain river systems such as the Komati River and is used to:

- administer water supplied, water requested and water used;
- plan releases for distribution through the systems by estimating the response (travel) times and water losses through the distribution systems; and
- prepare water accounts.

The model should be capable of determining (predicting) a timed release pattern at the commencement of, and for the duration of an operational cycle. Considering the size of the system, a practical cycle length is likely to be of the order of one to two weeks. The following are desirable features of the model:

- The release pattern can be designed to ensure that the release matches scheduled abstractions by taking into account the time required for water to flow from the release to abstraction point (i.e. the hydraulic characteristics of the river channel), the present and future natural flow in the river, and flow inputs (diffuse and tributary inflows) and abstractions (irrigators, domestic and industrial users) and diffuse outflows such as evaporation and evapo-transpiration losses and seepage en route.
- The water requirements for the Ecological Reserve can be prescribed at any number of points in the system. The ecological Reserve requirements are non-consumptive and therefore represent minimum flows that must be maintained at specified sites. The model should be capable of determining releases that will maintain these minimum flows.
- A significant proportion of existing irrigation water requirements downstream of the Klipvoor, Roodekopjes and Vaalkop Dams are met from runoff originating in the catchment downstream of the dams. Releases from the dams are therefore only required to supply user requirements when these exceed the flow generated downstream of the dams. The model should ideally be capable of being configured to estimate these accruals, but this may require regular re-calibration to account for anomalies.

3.1.2 Unsteady Flow Simulation Model

This would be the secondary river flow management decision support model for intermittent use. It is also a hydraulic river flow model operated in real present and future time. This model is used to simulate the flow of the releases from the Roodekopjes Dam (and possibly also the Klipvoor and Vaalkop Dams) that have been determined with the steady state model. This is done by means of hydraulic routing and visually inspecting the downstream routed outflow hydrograph to determine whether the water requirements can be met at the correct times at all the points of concern along the river. Although it can be used to adjust the outflow hydrograph this can be a time-consuming process and generally requires a graduate civil engineer (possibly with an advanced degree) specialising in hydraulics and hydraulic modelling.

The main application of this model will be to verify the output from the steady flow model on an ongoing seasonal basis after the initial calibration has been completed and to use it to recalibrate the steady flow model when necessary.

Typically a standard software package would be acquired that is adapted, configured and populated with data relevant to the Crocodile River (West). These models are usually based on a sophisticated flow simulation engine that performs hydro-dynamic routing through the solution of the St Venant equations. Such models are nevertheless in use within South Africa and the technology and support is available, although of a specialised nature.

Although not a function of the CRW RMA, a secondary application of this model could also be to simulate flood releases from the Klipvoor, Roodekopjes and Vaalkop Dams in support of DWA.

3.2 Water Resource Allocation Models

The following two water resources allocation decision support models are recommended to be used by DWA at each of the Mokolo Dam on the Mokolo River and the Klipvoor, Roodekopjes and Vaalkop Dams in the catchment of the Crocodile River (West), operated as a system or as individual dams (presumably including the runoff from the downstream catchments):

- A long-term water allocation model to determine the quantities of water that can be allocated to the various users at different risks of curtailment; and
- A short-term water use curtailment (rationing) model that will indicate when curtailments will be introduced for the various users and the severity of such curtailments, to comply with particular water supply and storage criteria.

3.2.1 Long-Term Water Allocation Model

This would be a hydrological system model with a monthly time resolution that is based on historic catchment runoff sequences. The main purpose of the water allocation model is to provide a basis for deciding on water entitlements for the consumers and thereafter to assess the effects of changed real time criteria, changed threshold water requirements for the Ecological Reserve and changed conditions in the catchments.

The allocation model is a steady state model, i.e. it is used to analyse systems where the system and system water requirements remain constant throughout the full simulation period. Changes in the system and/or system water requirements will, therefore, affect the allocation of water to the different users. Should any changes occur, the model needs to be modified and re-run in order to revise the water use entitlements of the various users.

The circumstances under which the model should be re-run in future include the following:

- When there are improvements or changes to the simulated catchment runoff sequences. Changes in the hydrological database could affect the system yield, since there is an increased probability that the longer flow sequences will contain more severe drought sequences than those included in earlier runoff sequences. The need for updating the hydrology needs to be assessed at regular intervals;
- Changes in land use that could change the runoff sequences (implicit in the above); and
- New water resources development infrastructure in the upstream and tributary sub-catchments and in the main stem rivers.

DWA will have the responsibility to monitor and respond to any changes in conditions and/or development within the catchments that could affect the allocation of water to the users. As such, the responsibility lies with DWA to decide if and when the model should be re-run to confirm or revise the water use entitlements.

3.2.2 Short-Term Water Use Curtailment Model

This should be a hydrological system water use curtailment (rationing) model with a monthly time resolution that is based on stochastically generated future time flow sequences to develop a short to medium-term strategy for the curtailment, if any, of water use shortly before or during severe drought conditions.

The responsible planning of water rationing or curtailment maximizes the use of the water resource and provides safeguards against depleting the water stored in the system in the event of a drought occurring that is more severe than had been experienced in the past.

The model must assess the likely timing and severity of future curtailments of water abstractions by the consumers for any short to medium-term future time interval – typically between 18 months and 42 months. Once a curtailment strategy has been agreed upon the model can be used regularly, say on a monthly basis, to decide whether there is any need to revise the earlier strategy or not.

The primary objective of the rationing model is therefore to determine the timing and degree of water use curtailment that is necessary to ensure that sufficient water remains in the system to avoid an unacceptable risk of extreme curtailments should a severe drought develop.

To fulfil this objective, the rationing model should have the following features:

- The same system infrastructure, water requirements and runoff sequences used in the water allocation model must be embedded in the rationing model.
- The existing state of the system (storage and antecedent river flow conditions) should be allowed for.
- Different degrees of curtailment should be able to be applied to the different categories of users.
- It should be possible to verify that users requiring a high reliability of supply will not be compromised by excessive current requirements from the system.
- It should be possible to investigate the effect on the risk of failure of the water supplies of a number of alternative water supply and curtailment strategies.
- A desirable feature is that different scenarios of water use can be rapidly processed to facilitate interaction between consumers and managers.

4. ABSTRACTION AND RIVER FLOW MEASUREMENT INFRASTRUCTURE

4.1 Data Acquisition

Account must be kept of water use, partly to keep track of it relative to weekly, monthly and annual entitlements and hence the accumulation or otherwise of unused water in the dams during the water year, and in certain cases partly to enable charges to be made to the users by DWA. The water releases or abstractions from the dams, abstractions from the rivers, river flow and the use of water from boreholes that are hydraulically connected to the river flow must therefore be measured where applicable.

The data should be imported into the steady flow release model (Section3.1.1) and model predictions compared and adjustments made as may be necessary. Real time or near real time data acquisition and daily updating of the flow model is therefore of critical importance. Over abstraction on a few consecutive hot days can have a severe impact on available river flow at Vlieëpoort.

Water abstraction data must be obtained by the RMA and be provided to the MCWAP Authority. This information will generally not be available in real time or near real time, but should also be available on a monthly basis shortly after the end of the month. This reporting interval is too long for real time operational use and therefore two data sets are required. These are the real and near real time data and the monitoring or historic data. Each data set has a different application and different levels of confidence attached to it. Both sets of data are required for water use reconciliations that will employ a water mass balance relationship.

The requirements for weather stations have not been addressed since weather data, current and forecast, can be obtained from the SA Weather Bureau and also from various web sites. This data can be used to forecast evaporation and evapo-transpiration losses from the river systems.

4.2 Available Infrastructure

The existing river flow measurement and recording infrastructure downstream of the Klipvoor, Roodekopjes, Vaalkop and Mokolo Dams are shown in Figures 4-1, 4-2, 4-3 and 4-4, and consists of the following:

- A2H019 (Roodekopjes Dam) in the Crocodile River (West);
- A2H021 (Buffelspoort) in the Pienaars River (will also gauge the flows from the Tolwane or Sandrivier) catchment;
- A2H059 (Atlanta Weir) in the Crocodile River (West);
- A2H060 (Nooitgedacht Weir) in the Crocodile River (West);
- A2H106 (Klipvoor Dam) in the Pienaars River;
- A2H111 (Vaalkop Dam) in the Elands River;
- A2H116 (Paul Hugo Weir) in the Crocodile River (West), and
- A4H010 and A4H011 (Mokolo Dam).

The non-functioning stations are not listed, which in the case of the Crocodile River (West) is not considered to be problematic and the working stations should suffice. However, in the case of the Mokolo River none of the gauging weirs further downstream of Mokolo Dam are functional and would make water mass balance calculations impossible. Station A4H013 would have been very useful in this regard.

Considerable repairs should be undertaken at A2H116 (Hugo's Weir) to improve the weir structure to DWA standards and to install the latest flow gauging instrumentation. The present installation appears to have stopped functioning in 1995 and was only capable of measuring flows up to 7 m^3/s.

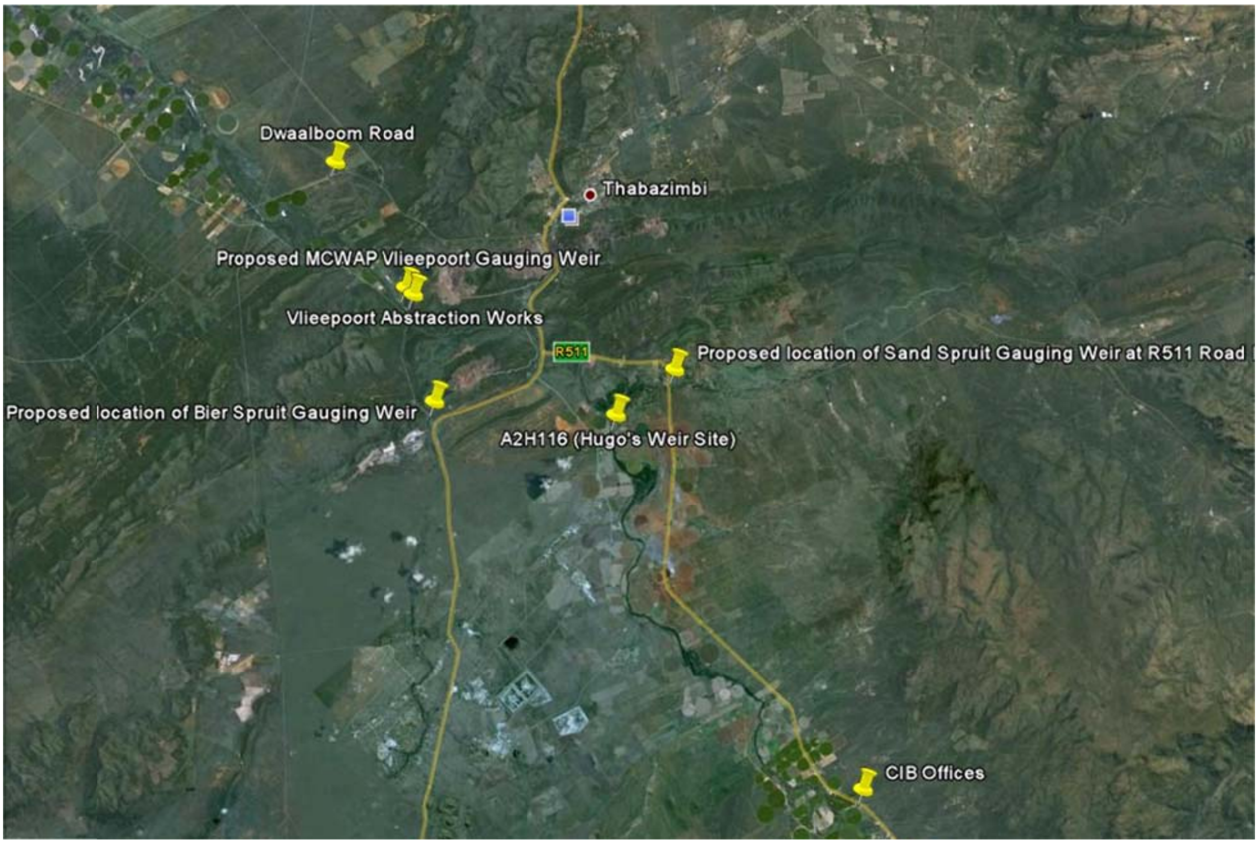

Figure 4-1: Gauging Weirs along the Crocodile River (West) between A2H116 and Vlieëpoort

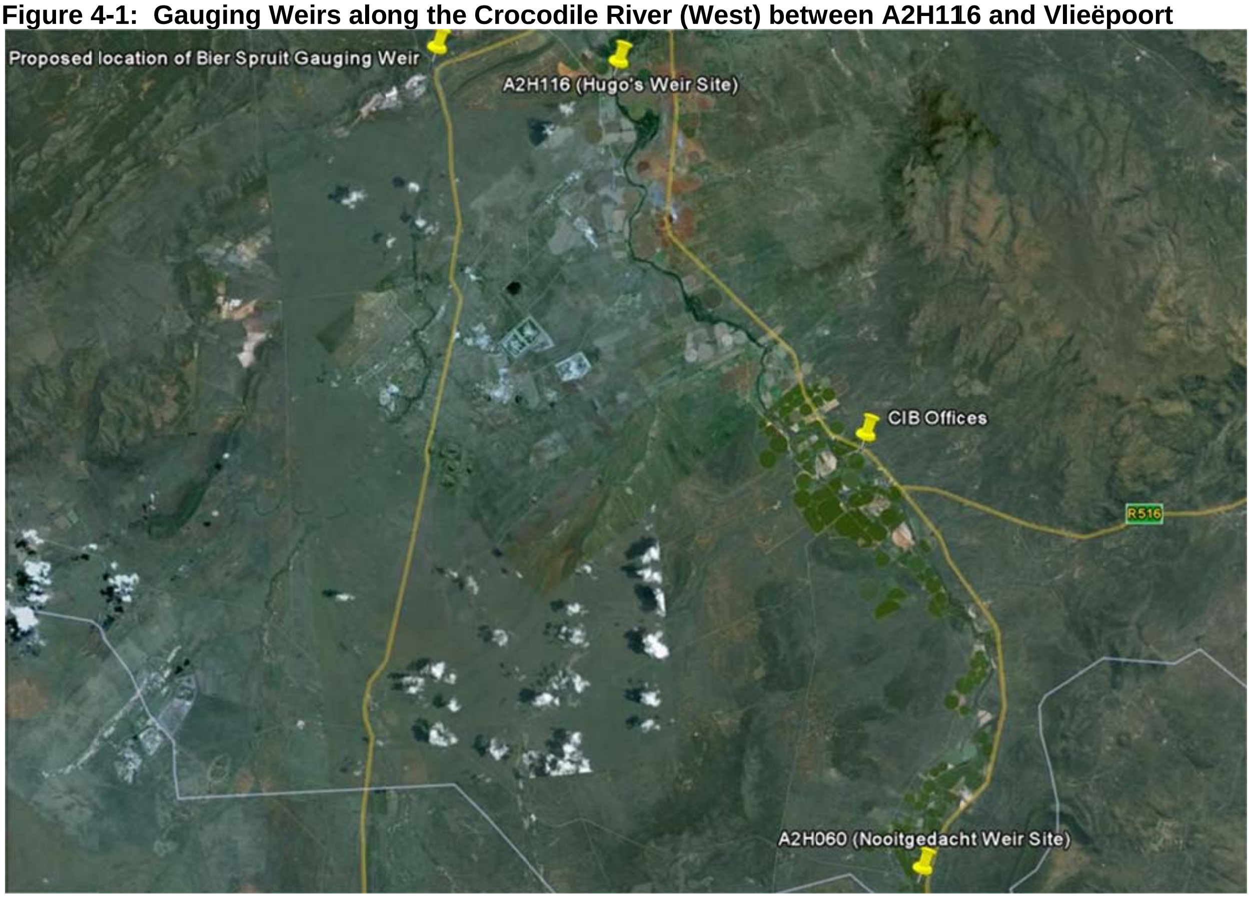

Figure 4-2: Gauging Weirs along the Crocodile River (West) between A2H060 and A2H116

Figure 4-3: Gauging Weirs on the Crocodile River (West) between the Upstream Supply Dams and Nooigedacht Gauging Weir A2H060

The river flow gauging stations should be of a standard equal to the latest standards adopted by DWA. Instrumentation should also be such that the data can be interrogated by the RMA at any time. The condition and appropriateness of the instrumentation should be confirmed. If possible a fibre optic cable link backed up by a GSM wireless link should be provided to allow for reliable real time recording of flow data.

Attention should also be given to minimising the potential risk of vandalism, particularly of the instrumentation.

Minimum flow measurement requirements for gauging weirs are shown in Table 4-1 below. The estimated normal flow measurement range would be 6 m^3/s to 30 m^3/s, excluding floods, with a measurement sensitivity of 0,25 to 0,50 m^3/s.

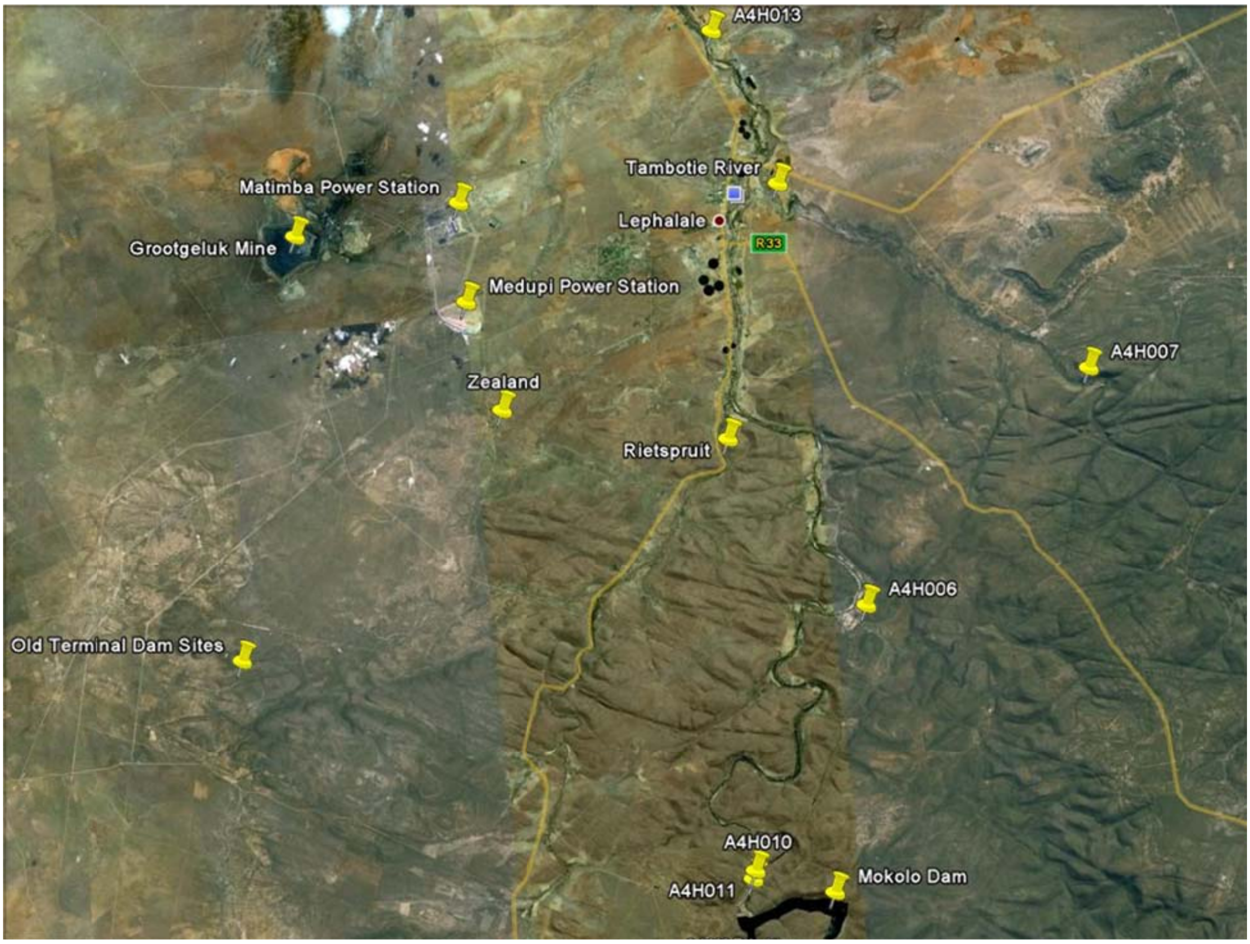

Figure 4-4: Mokolo River Gauging Weirs downstream of Mokolo Dam

Table 4-1: Gauging Weir Measurement Ranges in Crocodile River (West)

Flow Component	Minimum (m^3/s)	Maximum (m^3/s)	Remarks
1. River Base Flow	0,0	9,3 (1)	Maximum daily flow, excluding floods (2).
2. MCWAP	5,5	13,7	Maximum Stage 1 and 2 requirements.
3. Irrigation	3,8	3,8	Dams to Vlieëpoort.
4. IFR at Vlieëpoort	0,9	0,9	Estimated downstream flow requirements.
5. All losses	1,7	1,7	See Supporting Report No. 12.
TOTALS	**12**	**30**	Rounded up (3)

Notes:

1. Note that the maximum flow recorded at A2H060 (Nooitgedacht) in the period 1982 to 2008 was 765 m^3/s.
2. Calculation was based on the assumption that floods would only be reflected above the 90% percentile of the recorded flows. A2H060 used as reference.
3. A portion of flow components 3, 4 and 5 are already included in 1 (base flow).

4.3 Mokolo River Management Authority

The only flow measurement that is anticipated to be required will be the water abstraction from the Mokolo Dam. In the case of the MCWAP (including the existing delivery scheme) this should be in the suction pipes leading to the two pump stations.

The data should preferably be available in real time, both as a rate of flow and as a cumulative volume. The rate of flow must be recorded on a continuous basis. Instrumentation should also be such that the data can be interrogated by the MR RMA at any time.

Consideration should also be given to the acquirement of abstraction data from the irrigators and other users along the river for use in the water resource allocation models. Refurbishment of gauging weir A4H013 may well be required to support this.

4.4 Crocodile (West) River Management Authority

River flows should be measured immediately downstream of each of the Klipvoor, Roodekopjes and Vaalkop Dams to determine the effective water releases from them. In addition, the flow of the Crocodile River (West) should be measured at selected sites between the above dams and Vlieëpoort (see Section 5.3) in order to monitor the flow of water in the system on a real time or near real time basis and to take remedial action at the earliest possible opportunity whenever it is required to avoid undue loss of water or to avoid shortages within the system, particularly at Vlieëpoort. The flow of the Crocodile River (West) should also be measured at the first suitable gauging site downstream of Vlieëpoort to confirm that the downstream flow requirements are met and to determine the surplus flows, if any.

5. ADDITIONAL RIVER FLOW MEASUREMENT AND RECORDING INFRASTRUCTURE

5.1 General

All pumps abstracting water from the Pienaars River, Crocodile River (West) and the Elands River downstream of the Klipvoor, Roodekopjes and Vaalkop Dams and from the Mokolo River downstream of Mokolo Dam should be fitted with water and power consumption meters. The water meters should cumulate the total volume of water abstracted from the river on a continuous basis and preferably also indicate the rate of flow. The power consumption meters should function on the same basis and would be used as a cross-check on the water consumption figures. The water meters should be of the ultrasonic, magnetic or similar type to minimise the possibility of malfunctions. The water and power consumption meters should preferably allow for wireless interrogation.

Likewise, all pumps that are abstracting water from boreholes that have hydraulic connectivity to the nearby Pienaars River, Crocodile River (West), Elands River and Mokolo River should be fitted with meters of the types described above.

5.2 Mokolo River Management Authority

No additional river flow measurement and recording infrastructure is required from the MCWAP perspective. However, if required for the purposes of the water resource allocation models and Mokolo operating rules, it may be necessary to expand the data collected to also include the irrigators and other downstream users. In this case the equipping of the all relevant abstraction points and the refurbishment of gauging weir A4H013 as discussed in Sections 4.2 and 5.1 above should be considered.

5.3 Crocodile (West) River Management Authority

The river flow gauging stations listed in Section 4.2 are relatively well positioned for managing the river flow downstream of the Klipvoor, Roodekopjes and Vaalkop Dams to Vlieëpoort. However, it is considered necessary to construct a new river flow gauging station in the Crocodile River (West) at the first suitable site downstream of Vlieëpoort for the reasons indicated previously. All the river flow gauging station data should be relayed on a real time or near to real time basis to the MCWAP SMA for monitoring of the river flows and to enable the SMA to manage the abstraction process.

In addition to the above new river flow gauging station, provision should also be made at this stage for at least one other new river flow gauging station in case operational experience indicates that such a gauge will improve the efficiency with which the river system is managed and diffuse losses and unauthorised uses can be estimated.

Flows from the Bierspruit and Sandrivier should also be measured to ensure that these flows are allowed to pass the Vlieëpoort Abstraction Works. The motivation for these additional gauging weirs is provided in **Appendix D** of this Report.

The quality of all the river flow gauging stations listed above, including the instrumentation, will have to be confirmed and upgraded if necessary. The gauging station A2H116 (Paul Hugo Weir) may well require extensive rehabilitation work. Instrumentation must also be such that the data can be interrogated wirelessly by the CRW RMA at any time.

The supporting communications infrastructure provided should be based on a fibre optic and GSM network. The gauging weirs should be included in the fibre optic network to ensure that real time data is available at all times. The meters installed at the user abstraction points should be adequately served by a GSM network.

6. DATA PROCESSING, DISPLAY AND ARCHIVING

6.1 General

It is envisaged that the MCWAP Authority will establish a web site where all available data will be displayed and from where real time, near real time and historic data can be obtained by the water users and other interested and affected parties.

All real time or near real time flow data should be displayed by means of a systems control and data acquisition (SCADA) system in the operational control centre, where the MR RMA and CWR RMA personnel are expected to be located.

6.2 Mokolo River Management Authority

Data to be displayed and to be made available on the website would typically be the following:

- Water abstraction allocation to the MCWAP Authority from Mokolo Dam for the year;
- Water abstracted by the MCWAP Authority from Mokolo Dam during the year;
- Water abstraction allocations to others from Mokolo Dam for the year;
- Abstractions by and releases from the Mokolo Dam for others during the year; and
- Trajectory of actual storage in Mokolo Dam compared to trajectories of storage for different probabilities of exceedance.

6.3 Crocodile (West) River Management Authority

Data to be displayed and to be made available on the website would typically be the following:

- Water abstraction allocation to the MCWAP Authority from the Crocodile River (West) for the year;
- Water abstraction allocations to others for the year;
- Planned water releases from the Klipvoor, Roodekopjes and Vaalkop Dams for the year;
- Actual water releases from the Klipvoor, Roodekopjes and Vaalkop Dams during the year;
- Water abstracted by the MCWAP Authority from the Crocodile River (West) during the year;
- Diffuse and ungauged tributary accruals into the Pienaars River, Crocodile River (West) and Elands River downstream of the Klipvoor, Roodekopjes and Vaalkop Dams during the year;
- Diffuse outflows and unaccounted for abstractions from the Pienaars River, Crocodile River (West) and Elands River downstream of the Klipvoor, Roodekopjes and Vaalkop Dams during the year;
- Evaporation and evapo-transpiration losses from the Pienaars River, Crocodile River (West) and Elands River downstream of the Klipvoor, Roodekopjes and Vaalkop Dams during the year;
- Water abstracted by others during the year -
    - from the Crocodile River (West);
    - from boreholes hydraulically connected to the Crocodile River (West).
- Cumulative gauged flow volumes for the year and latest flows at -

- A2H019 (Roodekopjes Dam) in the Crocodile River (West);
- A2H021 (Buffelspoort) in the Pienaars River;
- A2H059 (Atlanta) in the Crocodile River (West);
- A2H060 (Nooitgedacht) in the Crocodile River (West);
- A2H106 (Klipvoor Dam) in the Pienaars River;
- A2H111 (Vaalkop Dam) in the Elands River;
- A2H116 (Paul Hugo Weir) in the Crocodile River (West); and
- New river flow gauging weir in the Crocodile River (West) downstream of Vlieëpoort.

7. RECONCILIATION OF DAM RELEASES, RIVER FLOWS, WATER USE, RIVER LOSSES, RIVER OUTFLOWS AND DIFFUSE AND TRIBUTARY ACCRUALS

7.1 General

This section outlines the general procedure that is necessary to analyse all flow data that has been monitored and recorded, comparing these with the water use entitlements of the authorised users, and then reconciling these as part of an overall water mass balance.

Two types of reconciliation procedures should be developed as described below. These are the so-called Operational Reconciliations and the Historical Reconciliations. Each type of reconciliation has a different application and different levels of confidence attached to the output. The reconciliations essentially provide an account of how the available water has been released and consumed downstream. Both types of reconciliations utilise the basic river reach water mass balance relationship, which is the following:

Flow at the end of a river reach - Flow at the start of the river reach = Diffuse and tributary accruals within the river reach - Abstractions (i.e. water use) within the river reach - Diffuse outflows within the river reach.

The flow at the end of a river reach, the flow at the start of the river reach and the abstractions within the river reach are measured quantities. Diffuse and tributary accruals within the river reach and diffuse outflows within the river reach are estimated quantities generally based on deterministic methods.

Operational Reconciliations are done before measured water abstraction data is available. The main purpose of these reconciliations is to estimate and monitor water abstraction at an early stage on an on-going daily basis if necessary, before actual measured water abstractions become available for that month. The confidence that can be placed on the estimates of water abstraction becomes a function of the confidence with which the diffuse outflows and diffuse and tributary accruals can be estimated at the time.

Historic Reconciliations will generally be done on a monthly basis to be able to report on the water balance during the preceding portion of the water year, using all the measured data that is available. They also provide a useful tool with which to calibrate the deterministic components in the water mass balance relationship and an opportunity to identify possible flow gauging inaccuracies and thereby further improve the confidence in the estimates of accruals and outflows.

The quantities in the mass balance relationship are determined as follows:

- The flows in the river at the start and end of each main river reach are measured;
- Diffuse and tributary accruals, i.e. unmeasured runoff from the portion of the catchment between the start and end of a river reach, are estimated using deterministic models. Measuring certain major tributary inflows could always be considered in future;
- Abstractions for which water use entitlements exist must be measured;
- The generally small water abstractions for diffuse livestock and domestic use (including small abstractions from boreholes where these are connected to the river water), are estimated where no measurements are available;
- Evaporation losses from the water surface and evapo-transpiration losses from the riparian vegetation are estimated using deterministic models; and
- Diffuse river channel outflows (including outflows to boreholes that are hydraulically connected to the rivers) must be estimated. The mass balance relationship may form the best tool to do this.

Data and quantities used in the reconciliations can be classified as follows:

- Measured or observed data that is gathered on an on-going basis and varies on a daily basis as a rule; and
- Quantities derived from deterministic models: these generally only provide month to month variations, but not from year to year. This is largely because of the nature of the models that are used to simulate the information.

Where measured data sets are incomplete, the data must nevertheless be assembled since the incomplete data set can frequently be patched, which is mostly better than no data. Where data must be patched, supplementary flow data and other data such as installed pump capacities and actual irrigated areas for which measured and unmeasured abstraction data is available, may be required to facilitate patching.

It is envisaged that the reconciliations will all be prepared on a number of worksheets in a single Excel file. These can also be arranged in a summarised format that is suitable for presentation at meetings, workshops and discussion forums.

7.2 Mokolo River Management Authority

Only the average daily volumes of water abstracted and released from Mokolo Dam and the monthly water use entitlements from the dam are required to perform the monthly Historic Reconciliations of water use and entitlements.

7.3 Crocodile (West) River Management Authority

The following data is required to perform the monthly Historic Reconciliations of water use and entitlements:

- Monthly water use entitlements of all the following different water user groups -
    - the Crocodile Irrigation Board;
    - the Lower Crocodile users, grouped according to river and/or subterranean reaches;
    - the Platinum mines, grouped according to river reaches and/or subterranean reaches;
    - the Thabazimbi Local Municipality;
    - any ecological flow requirements; and
    - international flow obligations.
- Estimates (forecasts) of average weekly and average monthly water use by the above user groups;
- Records of monthly volumes of water abstracted by the above water user groups -
    - from the Crocodile River (West);
    - from boreholes hydraulically connected to the Crocodile River (West).
- Gauged average daily flow volumes at:
    - A2H019 (Roodekopjes Dam) in the Crocodile River (West);
    - A2H021 (Buffelspoort) in the Pienaars River;
    - A2H059 (Atlanta) in the Crocodile River (West);
    - A2H060 (Nooitgedacht) in the Crocodile River (West);
    - A2H106 (Klipvoor Dam) in the Pienaars River;
    - A2H111 (Vaalkop Dam) in the Elands River;
    - A2H116 (Paul Hugo Dam) in the Crocodile River (West); and
    - New river flow gauging weir in the Crocodile River (West) downstream of Vlieëpoort.

Certain of the daily flow data may not be used directly as daily data in the reconciliations. It is, however, required for periods of high flow when it becomes necessary to establish, by inspection of the average daily flow data, any significant accruals downstream of the Klipvoor, Roodekopjes and Vaalkop Dams and when and how much of the flow in the system was surplus to the requirements for existing use.

The effects of lag times can become significant in the evaluation of the daily records to make assessments of accruals and surplus water.

8. COMMUNICATION WITH AFFECTED PARTIES AND USER REPRESENTATIVES

The web site that has been proposed to display the data will be a day-to-day form of communication with affected parties, in addition to telephone, tele-fax and e-mail communication facilities for use by the User Representatives and the River Management Authorities. In addition, it is proposed that communication forums (see Part 1 of this Report), comprising User Representatives and the River Management Authorities, should be established where specific issues, particularly those relating to day-to-day operations, can be discussed.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 General

It is recommended that detailed dam operating criteria, water management plans and infrastructure and personnel requirements be formulated to ensure that Phases 1 and 2 of the MCWAP can be supplied with water at acceptable levels of efficiency and without undue wastage after each of the phases is commissioned. Appropriate management manuals should be prepared to guide and assist the MR RMA and the CRW RMA to meet their responsibilities. These manuals will need to be updated from time to time as circumstances and developments dictate.

9.2 Decision Support Systems

River flow management decision support models to be operated by the RMA and water resource allocation decision support models to be operated by DWA are recommended.

Two types of river flow management decision support models are proposed:

- A steady flow water release model, which should be a real time model that will be used to administer water requests and to directly estimate the water release hydrographs from the dams, taking account of variable diffuse and tributary downstream accruals, diffuse losses and outflows, abstractions and river flow lag times.
- An unsteady flow simulation model, which is a hydraulic river flow model that will be used to simulate the flow of the releases from the dams (that have been determined with the steady state model). The model will be used to confirm the output from the steady flow water release model and with which it can be calibrated from time to time.

Two types of water resource allocation decision support models are proposed:

- A long-term Water Allocation Model. This should be a steady state hydrological system model with a monthly time resolution that is based on historic catchment runoff sequences. The main purpose of the water allocation model is to provide a basis for deciding on water entitlements for the consumers and thereafter to assess the effects of changed real time criteria, changed threshold water requirements for the Ecological Reserve and changed conditions in the catchments.
- A short-term Water Use Curtailment Model. This should be a hydrological system water use curtailment model with a monthly time resolution that is based on stochastically generated future time flow sequences to develop a short to medium-term strategy for the curtailment of water use during severe drought conditions. The main purpose of the rationing model is therefore to determine the timing and degree of water use curtailment that is necessary to ensure that sufficient water remains in the system to avoid an unacceptable risk of extreme curtailments should a severe drought develop.

9.3 Flow Measurement

Two sets of data should be collected, each with its own specific application and different levels of confidence attached to it. The data sets are:

- Real and near real time data (electronic acquirement), and
- On site monitoring and historic data.

The real time or near real time data should be imported into the steady flow release model and model predictions compared and adjustments made as may be necessary. Over abstraction on a few consecutive hot days can have a severe impact on available river flow at Vlieëpoort. Real time or near real time data acquisition and daily updating of the flow model is therefore of critical importance.

Both sets of data are required for water use reconciliations that will employ a water mass balance relationship.

All pumps abstracting water from the Pienaars River, Crocodile River (West) and the Elands River downstream of the Klipvoor, Roodekopjes and Vaalkop Dams and from the Mokolo River downstream of Mokolo Dam should be fitted with water and power consumption meters. Likewise, all pumps that are abstracting water from boreholes that have hydraulic connectivity to the nearby rivers should be fitted with meters of the types described above. The water and power consumption meters should preferably allow for wireless interrogation.

Existing flow gauging weirs that are recommended for use are:

- A2H019 (Roodekopjes Dam) in the Crocodile River (West);
- A2H021 (Buffelspoort) in the Pienaars River (will also gauge the flows from the Tolwane or Sandrivier) catchment;

- A2H059 (Atlanta Weir) in the Crocodile River (West);
- A2H060 (Nooitgedacht Weir) in the Crocodile River (West);
- A2H106 (Klipvoor Dam) in the Pienaars River;
- A2H111 (Vaalkop Dam) in the Elands River;
- A2H116 (Paul Hugo Weir) in the Crocodile River (West), and
- A4H010 and A4H011 (Mokolo Dam).

Extensive improvements to Hugo's Weir will be required to allow flow measurement to the DWA standards.

It is also recommended that a new river flow gauging station be constructed in the Crocodile River (West) at the first suitable site downstream of Vlieëpoort. In addition to the above new river flow gauging station, provision should also be made at this stage for at least one other new river flow gauging station in case operational experience indicates that such a gauging weir will improve the efficiency with which the river system is managed and diffuse losses and unauthorised uses can be estimated.

Flows from the Bierspruit and Sandrivier should also be measured to ensure that these flows are allowed to pass the Vlieëpoort Abstraction Works. The motivation for these additional gauging weirs is described in **Appendix D** of this main report.

Supporting communications infrastructure provided should be based on a fibre optic and GSM network. The gauging weirs should be included in the fibre optic network to ensure that real time data is available at all times. The meters installed at the user abstraction points should be adequately served by a GSM network.

9.4 Data Processing

It is recommended that the MCWAP Authority establish an internet web site where all available data will be displayed and from where real time, near real time and historic data can be obtained by the water users and other interested and affected parties.

Typical data to be displayed include:

- Water abstraction allocations and actual abstractions;
- Planned and actual releases;
- Diffuse accruals and outflows;
- Evaporation and evapo-transpirations losses, and
- Cumulative gauged flow volumes.

9.5 Reconciliation of Releases and Flows

Operational and historical reconciliation procedures are recommended to analyse all flow data that has been monitored and recorded, comparing these with the water use entitlements of the authorised users, and then reconciling these as part of an overall water mass balance.

9.6 Communication

Day-to-day communication with affected parties should take place by means of the proposed web site, telephone, tele-fax and e-mail facilities. These facilities should be available to the User Representatives and the River Management Authorities. In addition, it is proposed that communication forums, comprising User Representatives and the River Management Authorities, should be established where specific issues can be discussed.