# Table of Contents



## Annexes

# 1 Introduction

In the delta of Brahmani and Baitarani rivers in Orissa almost every year inundations take place causing considerable damage. Floodings can be reduced by temporary storage of water behind Rengali dam on Brahmani river, which controls roughly some 50% of the total catchment area draining to the delta. To use the dam for flood mitigation, floods are being forecasted based on real-time information of rainfall and discharge in the two basins. The lead-times for forecasting at present are limited as only the contributions of the basins in Orissa are covered by the forecasting system. This includes the entire Baitarani basin and Brahmani river below Panposh. Upstream of Panposh, the Koel and Sankh rivers drain, which constitute over 75% of the catchment area controlled by the Rengali dam. By expanding the flood forecasting system to the upper reaches of the Brahmani basin lead-times can be extended and knowledge about the flood volumes to be temporarily stored at Rengali can be improved considerably.

The shortfalls of the present system were realised long time back. In August 1992 the Central Planning Unit, Irrigation Department, Orissa finalised a feasibility study on "Telemetry System for Rengali Dam Project". In this study it proposes a communication system for real-time collection of hydro-meteorological data in the Brahmani basin which covers such an expansion to improve the flood forecasting.

This was further taken up in World Bank's Staff Appraisal Report (SAR) of the Hydrology Project (July, 1995). In the SAR activities related to the improvement of flood forecasting in Brahmani basin are covered under the heading: "Improvement to Real-Time Water Resources Management", with a total budget of Rs.24.7 million. The proposed activities include:

1. Provision of additional telemetering equipment in the Brahmani basin, in two phases:
   - Phase I: installation of ten telemetering stations in the basin in Orissa to provide a lead time of about 24 hours for the inflow forecasts to the reservoir and the delta.
   - Phase II: extension of the telemetering system to include the upper catchment of Brahmani river in Bihar in order to provide a longer forecast lead time.
2. Flood Forecasting Study for the Brahmani River, including the development of a real-time flood forecasting system. Catchment modelling techniques, to be validated by using all available historical rainfall and flow data, will be applied in operating the system. The results of the study would be used to define the locations for the telemetering stations to be installed in the basin.

The Consultant visited the study area late June 1998 and discussed the problems and options for flood forecasting and telemetry thoroughly with the concerned officers of Orissa State, see Annex 1. Background information was retrieved from the 1992 feasibility study. At the same time it was realised that since 1992 communication technologies have improved, whereas furthermore, the quoted report is not explicit on the proposed modelling system. Therefore, a review of the original proposal would be required. Based on the discussions a document was drafted covering Consultant's view on the forecasting options. This document describes the flood forecasting system components and provides a fresh look at the required communication system to generate data for operation of an effective flood forecasting system for the two river basins, operated from Rengali dam site.

For full coverage of the background of the flood forecasting system and basin particulars reference is made to the above mentioned feasibility study. Some relevant aspects are repeated here in Chapter 2 (basin characteristics) and Chapter 3 (Rengali dam) to ease the reading. In brief the proposed flood forecasting system is dealt with in Chapter 4 and the requirements for the telemetry system in Chapter 5. In Chapter 6 a development strategy for the implementation of the forecasting system is outlined.

# 2 Brahmani and Baitarani catchments

**Basin characteristics**

The headwaters of Brahmani river are mainly formed by the Koel, Karo and Sankh rivers. The Brahmani known as South Koel in the upper reaches rises near Nagri village in the Ranchi district of Bihar. After its confluence with Sankh river at Panposh, the Koel river is called Brahmani river. Flowing in south-easterly direction, it reaches the delta at Jenapur and drains ultimately into the Bay of Bengal near Dhamara after traversing a distance of some 800 km. It drains a total catchment area of about 38,000 $km^2$, of which nearly 22,200 $km^2$ lies in Orissa.

The Baitarani river originates from Guptaganga hills near Gonasika village in Keonjhar district of Orissa. Initially the river flows in a northern direction for about 80 km and then takes an abrupt right turn near Champua and flows in a south easterly direction and finally discharges into Bay of Bengal through the deltaic area of river Brahmani. The river travels a total distance of 360 km and drains an area of over 14,000 $km^2$.

The layout of the Brahmani and Baitarani catchments is shown in Figure 2.1. Catchment particulars are summarised in the Tables A1 and A2 of Annex 2.

**Rainfall distribution**

There are 41 raingauge stations in the catchment area of river Brahmani and 15 in the Baitarani basin for which daily rainfall data are available.

A study of rainfall based on data from 1901 to 1950 (IMD, 1962) in and around the Brahmani and Baitarani basins reveals, that the area is more or less homogeneous. About 80% of the annual normal rainfall occurs during the 4 months of south-west monsoon season (June to September). The annual normal rainfall varies from 1250 mm to 1750 mm over the Brahmani basin and from 1250 mm to 1500 mm over the Baitarani basin. The coefficient of variation of annual rainfall is only about 20%, which shows that the rainfall in the region is fairly dependable.

**Temperature and humidity distribution**

The mean maximum temperature varies from $35^0$C to $42.5^0$C over the catchment areas of rivers Brahmani and Baitarani in the month of May. The mean minimum temperature varies from $15^0$C to $10^0$C over Brahmani catchment and from $15^0$C to $12.5^0$C over Baitarani catchment in the month of January. However, the extreme temperatures in summer (max.) and winter (min.) recorded in May and January are of the order of $47.5^0$C and $5^0$C respectively. The humidity is about 80 to 90% during monsoon season and 40 to 70% during non-monsoon season, the higher humidity being over the coastal region.


Figure 2.1 Layout of Brahmani and Baitarani river basins\

**Weather situations causing rainfall**

Heavy rainfall in the catchment areas of Brahmani and Baitarani rivers is generally caused by the formation and movement of depressions/cyclonic storms that originate in the Bay of Bengal and move inland across the Orissa coast in a westerly to north-westerly direction. On some occasions, low pressure areas that form over Bihar Plateau and adjoining region, also cause rainfall in the upper catchment areas of these rivers in due course of their westerly movement.

The frequency of formation of the depressions/cyclonic storms formed in the north Bay of Bengal during the Southwest monsoon months June to September increases as the monsoon progresses. On an average 1 to 2 depressions form in the months of June and July and 2 to 3 in August and September. These systems may take 2 to 3 days to form over the Bay of Bengal and intensify into a depression or cyclonic storm and then move inland in a north-westerly direction across Orissa coast. Once the system crosses the coast, it starts weakening and dissipates in 2 to 3 day's time. At times, it sustains and move across the whole of the central and north-western parts of India. These systems cause widespread rains all along the track with the central region receiving very heavy rainfall. The life cycle of these systems over the land varies from 2 to 4 days and river catchments coming under the influence of these systems receive persistent rainfall leading to floods. The catchments of river Brahmani and Baitarani generally remain under the influence of these moving depressions/cyclonic storms for 1 to 2 days depending upon their speed and direction of movement. A widespread system generally covers an area of 50,000 km$^2$ or more and may yield 150 to 200 mm rainfall in one day over this extensive area.

All the severe storms that have occurred since 1901 over the catchment areas of Brahmani and Baitarani and other neighbouring basins have been studied by IMD. Enveloping curves for 1-day and 2-day rainfall amounts have been drawn. The rainfall depths corresponding to different standard areas were picked up as given in Table 2.1

| Area (km$^2$.) | Rainfall depths (mm) | |
|---|---|---|
| | 1 – day | 2 – day |
| 1,000 | 521 | 737 |
| 5,000 | 434 | 653 |
| 10,000 | 366 | 574 |
| 20,000 | 292 | 465 |
| 50,000 | 198 | 366 |
| 100,000 | 142 | 279 |

Period 1901-1950

Table 2.1 1 and 2-day rainfall maxima as a function of area

**Flood problem in the delta**

The Brahmani delta starts at Jenapur, where the Kharasuan river branches off. The Karasuan receives runoff from the Baitarani through the Burha branch. Near Rajnagar Kharasuan joins Brahmani again. Downstream of Jenapur near Dharmasala the Relua river bifurcates from Brahmani. Relua is joined by the Mahanadi branch Birupa before it debouches again in Brahmani at Indupur. Shortly after Brahmani's confluence with Kharasuan the Maipura branches off, which drains to the Bay of Bengal. The remainder of Brahmani is then joined by the Baitarani river to debouch into the Bay of Bengal as Dhamra river. From the above it follows that the flood stages in the Brahmani delta are governed by:

1. inflow from:
   - Brahmani river, observed at Jenapur; total drainage area at Jenapur is 35,700 km$^2$, of which 25,100 km$^2$ is controlled by Rengali dam, leaving 10,600 km$^2$ fully uncontrolled.
   - Baitarani river, draining a catchment of 14,200 km$^2$ through Burha branch, observed at Akhuapada, and through the main branch draining to Dhamra river
   - Mahanadi river through Birupa branch, which inflow is nil during floods as its flow can be fully controlled at the upstream end
2. rainfall in the delta (catchment area about 2,000 km$^2$)
3. water level in the river mouths at the Bay of Bengal.

From this it is observed that runoff from over 50,000 $km^2$ of land enters the delta of about which about 50% is fully uncontrolled. The other 50% is in full or in part controllable through Rengali dam.

There are embankments on both sides of Brahmani river in the delta to protect the population against flooding. Given the carrying capacities of the river branches it has been estimated that in the delta flood damage will be small if the total discharge to the delta does not exceed 8,000 $m^3/s$. This figure will of course be dependent on the conditions at the river mouth. It is not clear what downstream boundary conditions have been considered in deriving this save amount. At high tide the water level slopes in the flat delta are further reduced which retards the outflow to the sea.

# 3 Rengali dam and reservoir characteristics

The Rengali dam on Brahmani river is a multipurpose dam to store water for irrigation and for the production of hydro-electric energy and to mitigate floods. Reangali dam is a gravity masonry type of dam with a length of 1,040 m. It has a 464 m long overflow section with an Ogee type spillway consisting of 24 gates. The spillway capacity is nearly 47,000 $m^3/s$ at a maximum reservoir level of 125.4 m. The installed hydropower capacity is 5x50 MW. The dam controls a catchment area of over 25,000 $km^2$.

**Reservoir storage**

The storage capacity of the reservoir is well described by the following equation:

$$S = 652{,}600 \times (H_{res}(m) - 92.423)^{2.566} \qquad 109.7 \le H_{res} \le 125.4$$

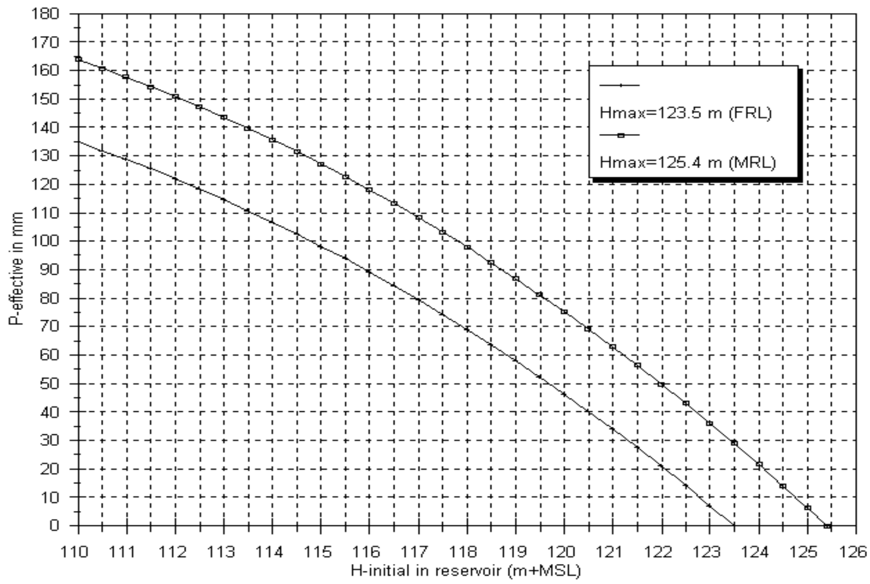
where: $S$ = storage capacity ($m^3$)
$H_{res}$ = reservoir level (m+MSL)

For the operation of the reservoir a rule curve as shown in Table 3.1 is used. The storage capacity of the reservoir expressed as an effective precipitation amount over the catchment controlled by the dam is presented in Figure 3.1. The storage capacity is given between the actual initial reservoir level and FRL (=123.5 m, i.e. the full reservoir level) and MRL (= 125.4 m, i.e. the maximum reservoir level) levels. The

| Date | Maximum Reservoir Level m+MSL |
|---|---|
| 1 July | 109.72 |
| 1 August | 116.00 |
| 1 September | 122.00 |
| 9 September | 122.30 |
| 22 September | 123.00 |
| 1 October | 123.50 |
| 1 November | 123.50 |

Table 3.1 Rule curve for Rengali reservoir

Figure shows that, during the first months of the monsoon, the flood mitigating capacity is considerable, and even severe storms can almost fully be stored. The capacity rapidly decreases during August and September and releases from the reservoir during and if possible prior to the arrival of a severe flood will be required to reduce the peak. To get an idea of the of the order of magnitude, note that a reservoir outflow of 3,000 $m^3/s$ during one day is equivalent to the discharge of an effective rainfall depth over the upper basin of 10 mm. Releases prior to and during the occurrence of a flood requires proper forecasts of the




flood volumes and peak discharges upstream and downstream of the dam.

Figure 3.1 Storage capacity of Rengali reservoir expressed in mm rainfall in the controlled basin area

**Reservoir operation**

At present the operation of Rengali reservoir is guided by the following two considerations (CPU, 1992):

1. **Dam safe condition**: in no case the safety of the dam should be allowed to be threatened. There should always be ample space in the reservoir for moderation of the incoming flood. Releases from the reservoir should be designed accurately.
2. **Safe flood condition**: an attempt should be made to restrict the release to safe flood conditions in the downstream area (i.e. a total inflow to the delta of less than 8,000 $m^3/s$); this should be done only if the dam safe condition so permits.

The first condition requires a reliable forecast of the maximum inflow volume to the reservoir, so that under all conditions the reservoir level can be kept below an MRL of 125.4 m. Both conditions benefit most from a low initial reservoir level. This conflicts however with the other two objectives of the multipurpose dam: storage of water for irrigation and hydropower. Therefore, pre-releases from the reservoir to create extra storage capacity for flood mitigation will only be acceptable if the rule curve levels will at least be attained again after the passage of the flood. This requires thus a reliable forecast of a guaranteed minimum inflow volume to the reservoir. The safe flood condition requires also a reliable forecast of the total inflow from the uncontrolled catchments, i.e. of the Brahmani downstream of Rengali and of the entire Baitarani. It is noted that effective manipulation of the gates at Rengali require proper information about the flow conditions well in advance. The travel time of Rengali releases to the delta is about 20 hours. This is almost equal to the basin lag (= time between centroids of net rainfall and runoff) of the Brahmani basin draining downstream of Rengali (about 24 hours) and only slightly less than the basin lag of Baitarani (approximately 30 hours), see Annex 2.

# 4 Flood forecasting system

## 4.1 Present forecasting method

The present flood forecasting method is based on a system of stage-relation curves for the the following river stretches:

| | Travel time |
|---|---|
| On Brahmani: Panposh – Rengali | 13 – 15 hrs |
| Rengali – Talcher | 3 hrs |
| Talcher – Jenapur | 16 – 18 hrs |
| | |
| On Baitarani: Champua – Swampatna | 4 – 5 hrs |
| Swampatna – Anandapur | 7 hrs |
| Anandapur – Akhuapada | 12 hrs |

Apart from river stages also rainfall amounts are communicated to Rengali through voice radio.

The weak points of the present system are:

- The system produces insufficient lead time for the flow at Rengali. It does not account for the Brahmani basin upstream of Panposh, which comprises about 75% of the basin area controlled by Rengali dam. The lag time between rainfall in this area and its contribution to the Brahmani flow at Rengali is about 30 hrs for Koel and 24 hrs for Sankh river.
- Contributions of the sub-basins below Panposh and in the Baitarani catchment are difficult to estimate, though rainfall is to some extent considered in the correlation technique used to produce the forecasts.
- The lead times are also small because neither rainfall-runoff modelling is considered nor are quantitative precipitation forecasts taken into account.
- The inflow to the delta, contributions by the delta area itself and the water levels at sea determine the flood stages in the delta. The present system does not provide any means to translate the boundary conditions into flood levels.

In the previous chapter it was noted that effective flood mitigation through Rengali dam requires proper information about the flow conditions upstream as well as downstream of the dam well in advance. The Rengali releases travel in about 20 hrs to the delta, which is only slightly less than the basin lags of the uncontrolled areas (respectively about 24 and 30 hours for Brahmani d/s of Rengali and Baitarani).

## 4.2 Flood mitigation with Rengali dam, possibilities and history

To analyse the flood mitigation capabilities of Rengali dam and reservoir a hypothetical flood and 3 historical flood situations are discussed here in this sub-chapter.

**Hypothetical flood**

In Annex 2 simple rainfall-runoff and river routing models for Brahmani and Baitarani rivers have been applied to describe the transformation of net rainfall into runoff and to route the contributions of the sub-basins to Rengali and to the delta. Using these models an example has been worked out which demonstrates the importance of using real-time rainfall and QPF (Quantitative Precipitation Forecast) information for dam operation. The example is presented in the Figures 4.1 to 4.3. A uniform rainfall amount of 20 mm/hr during 3 hours, i.e. 60 mm in total is considered, at a time that the reservoir level is 122.00 m, which is the situation at 1 September according to the existing rule curve. From Figure 3.1 it is observed that this amount of rainfall cannot be stored in the reservoir without releasing water. However, with the rainfall-runoff model it is computed that only half of the 60 mm of rain will run off at short notice. Now Figure 3.1 learns that in principle at an initial level of 122.00 m the full flood volume upstream of Rengali can be stored in the reservoir, without exceeding MRL. However, as depressions are more frequent in the second half of the monsoon period, full storage till the flood has passed would not be a proper policy. The best strategy would be to release the flood from Rengali reservoir as quickly as possible as soon as the conditions downstream of the dam do permit, to have maximum benefit for floods to come. Figure 4.1 shows that the uncontrolled inflow to the delta reaches its peak of about 7,500 $m^3/s$ at 26 hrs after the start of the rainstorm and a gradually increasing contribution from Rengali may enter the delta as from hr. 27 onward. It implies that the decision to release water from the reservoir was made 20 hours earlier in view of the travel time between Rengali and Jenapur, see Figure 4.2. To keep the river levels downstream of the dam limited a maximum outflow intensity of 5,000 $m^3/s$ was assumed. Then the outflow is gradually reduced to nil to reach the initial reservoir level of 122.0 m after the passage of the flood. The decay rate of the outflow should not be larger than the natural decay of the hydrograph in order not to endanger the stability of river embankments. The effect of the strategy on the inflow to the

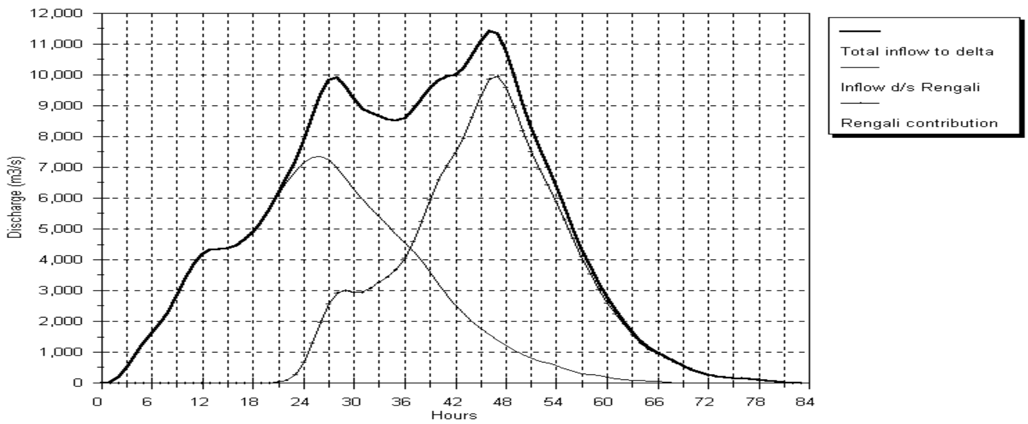



Figure 4.1 Brahmani delta inflow without dam operation due to net rainfall of 10 mm/hr during 3 hours

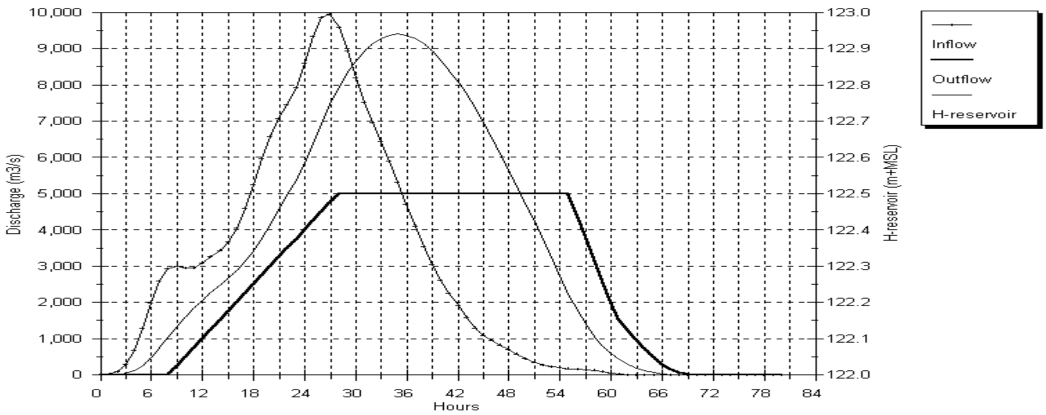



Figure 4.2 Operation of Rengali reservoir, $H_{res,init}$ = 122.00 m and $P_{eff}$ = 30 mm

delta is shown in Figure 4.3, from which it is observed that safe flood conditions in the delta could be maintained.

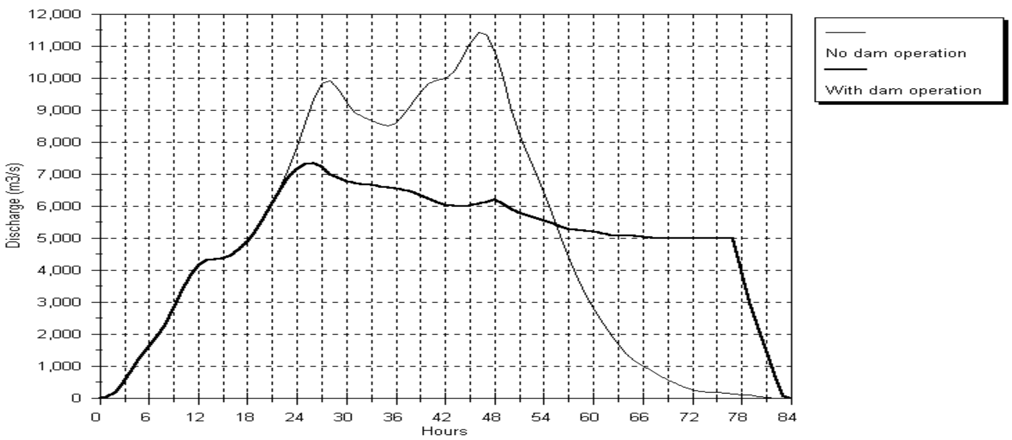



Figure 4.3 Effect of reservoir operation on inflow to Brahmani delta

From Figure 4.1 it is observed that releases from the reservoir prior to the peak of the uncontrolled inflow to increase the storage capacity in the reservoir would have been possible only if QPF had been available. An effective pre-release based on observed rainfall data under the assumed rainfall scenario would have hardly been possible.

**Flood of 20 July 1997**

The Rengali reservoir inflow, outflow and levels and the river stages along Brahmani and Baitarani rivers for the period 19 – 22 July 1994 are shown in the Figures 4.4 to 4.6. It is observed that by reservoir operation the flood peaks from Upper Brahmani were reduced from 11,000 to about 5,000 $m^3/s$, which certainly has reduced the flood damage to a large extent. However, the outflow could have been further reduced if well in time the flood volume would have been known. In Figure 4.7 such an alternative strategy is shown; here the outflow was restricted to 2,000 $m^3/s$, which would have resulted in a maximum reservoir level less than FRL. Note from Figures 4.5 and 4.6 that the communication system did not function proper as at a number of instances data are missing.

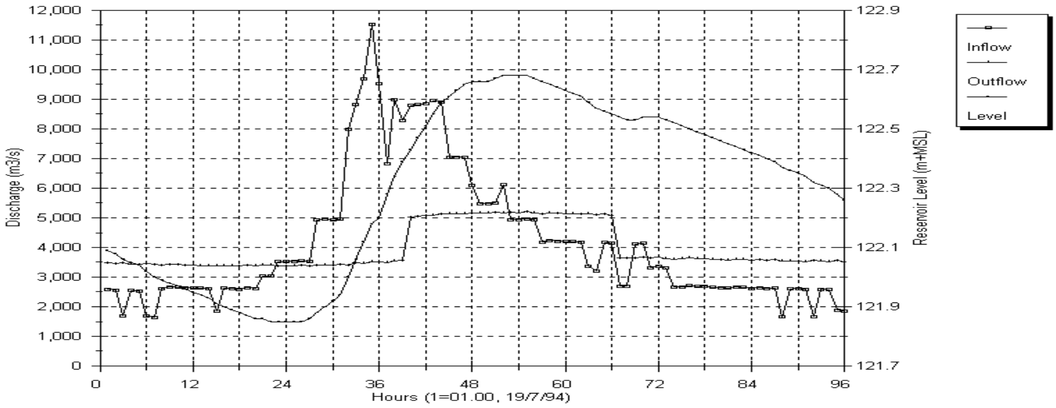



Figure 4.4 Rengali reservoir operation flood 19-22 July, 1994

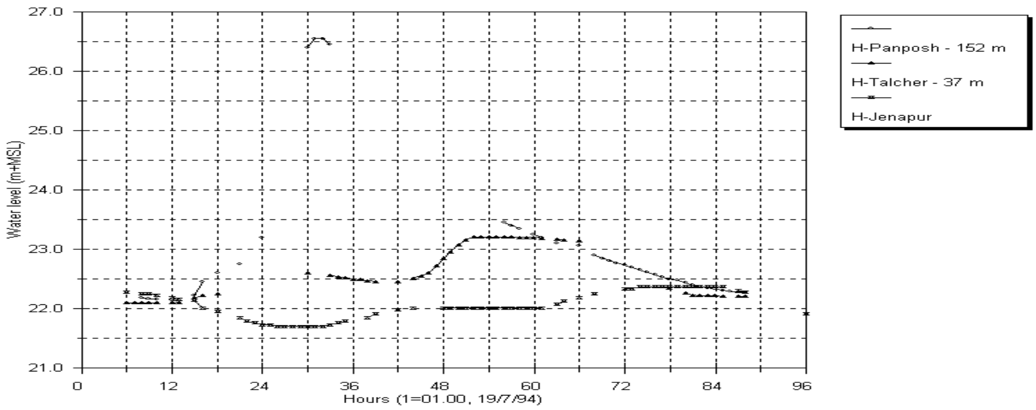



Figure 4.5 River stages along Brahmani river, flood 19-22 July, 1994

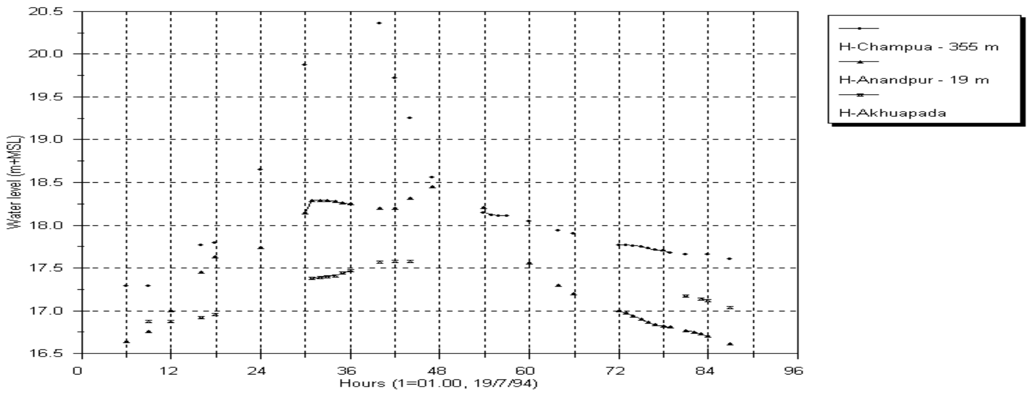



Figure 4.6 River stages along Baitarani river, flood 19-22 July, 1994

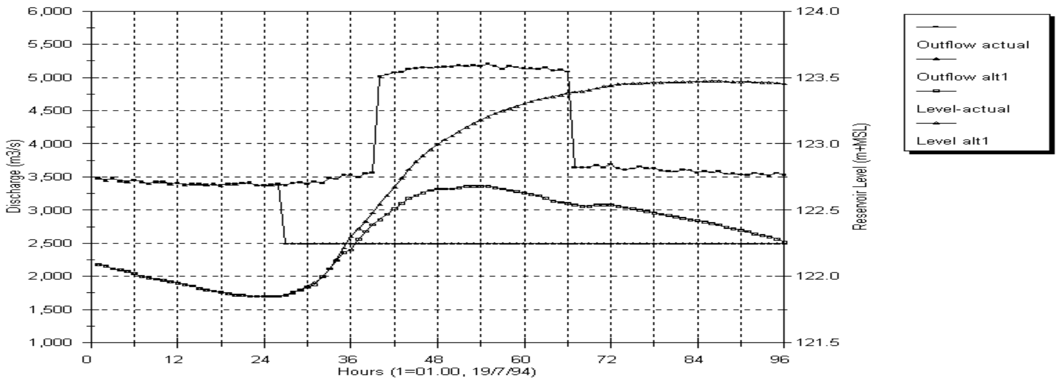



Figure 4.7 Historical and alternative operation strategy for Rengali dam, flood 19-22 July, 1994

**Flood of 4 August, 1994**

The Rengali reservoir inflow, outflow and levels and the river stages along Brahmani and Baitarani rivers for the period 30 July – 6 August, 1994 are shown in the Figures 4.8 to 4.10. It is observed that by reservoir operation the flood peaks from Upper Brahmani were reduced from 10,000 to about 6,000 $m^3$/s. It is noted that the initial reservoir level was about 6 m above the rule curve level. This implies that storage for about a net amount of 70 mm of rain was lost. Hence a much larger reduction could have been obtained. The reason why the level was kept 6 m above normal is not known. But even with an initial high reservoir level a larger reduction could have been achieved if more information about the time history of the flood waves would have been available. An example is given in Figure 4.11, where during the occurrence of the flood from the uncontrolled part the contribution from the upper reaches of Brahmani was kept as low as possible to limit the damage downstream and to keep the reservoir levels within acceptable boundaries.

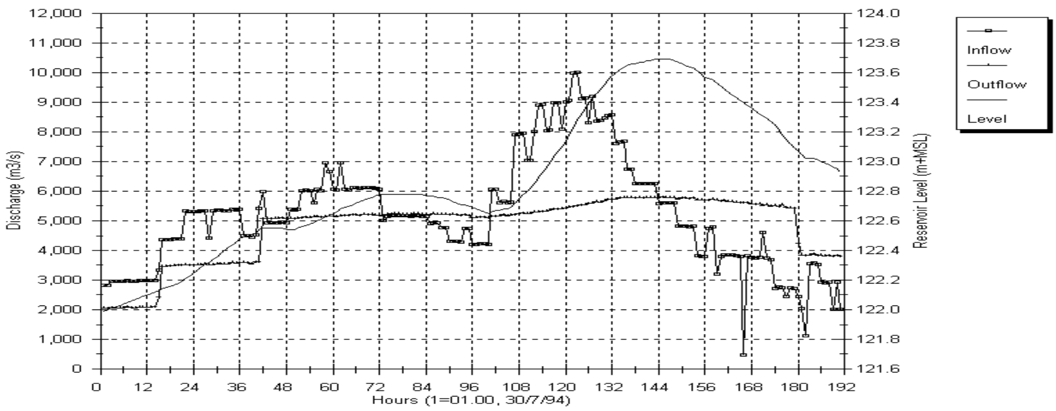



Figure 4.8 Rengali reservoir operation flood 30 July- 6 August, 1994

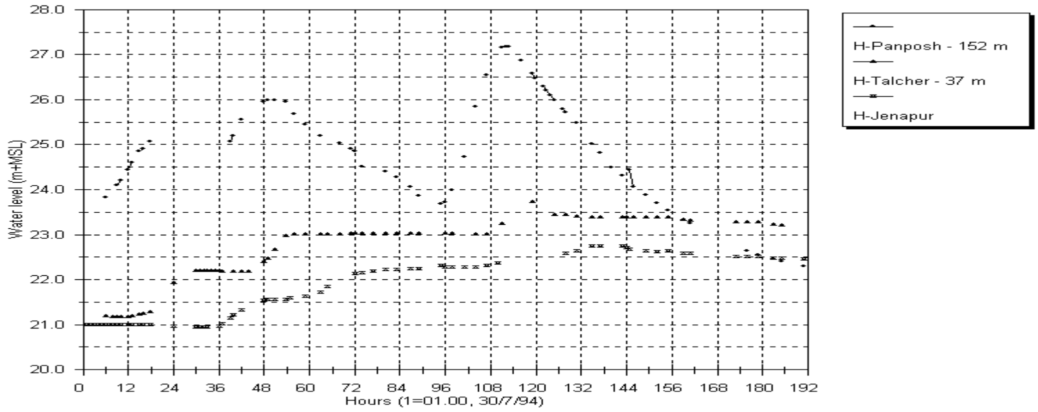



Figure 4.9 River stages along Brahmani river, flood 30 July- 6 August, 1994

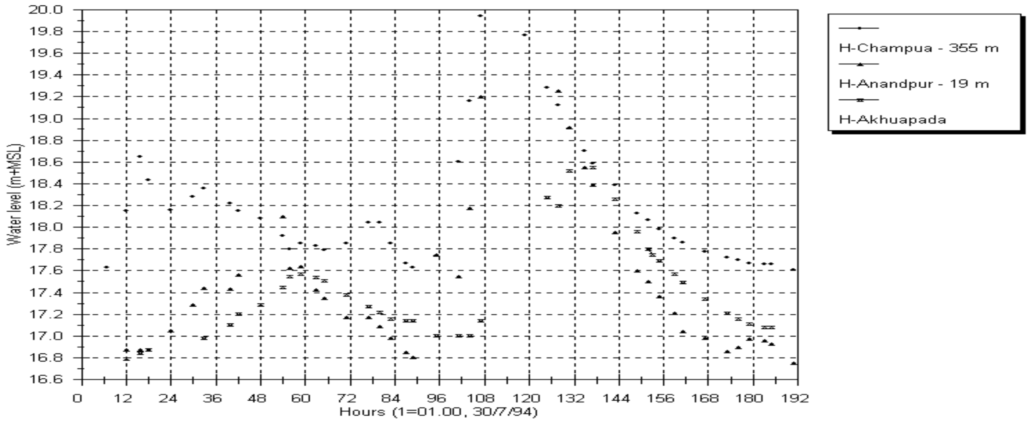



Figure 4.10 River stages along Baitarani river, flood 30 July- 6 August, 1994

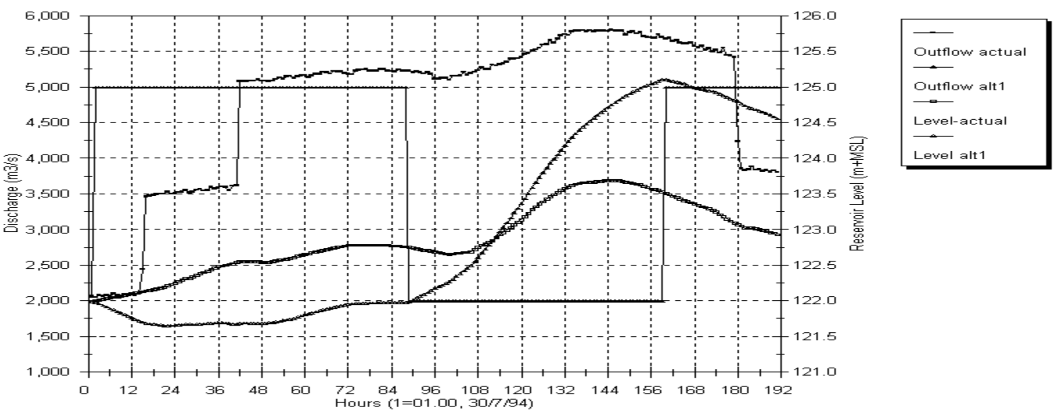



Figure 4.11 Historical and alternative operation strategy for Rengali dam, flood 30 July- 6 August, 1994

## Flood of 6 August, 1997

The river stages and reservoir operation during the August, 1997 flood is shown in Figures 4.12 – 4.14. It is observed from these figures that the reservoir has functioned to its maximum extent as flood controller. Almost the entire flood volume was stored in the reservoir, and released only when the uncontrolled delta inflow had receded to low values. The flood peak was reduced from 13,000 to 3,500 $m^3/s$. Note, that in this case the reservoir level was close to its rule curve level.

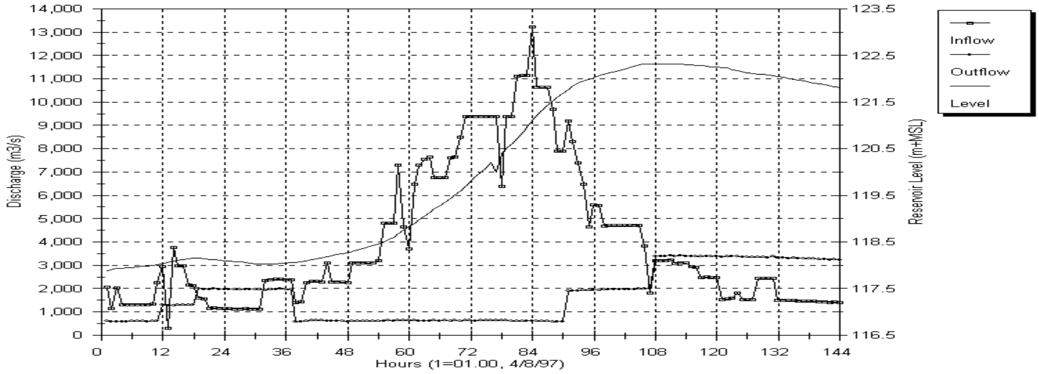



Figure 4.12 Rengali reservoir operation flood 4-10 August, 1997

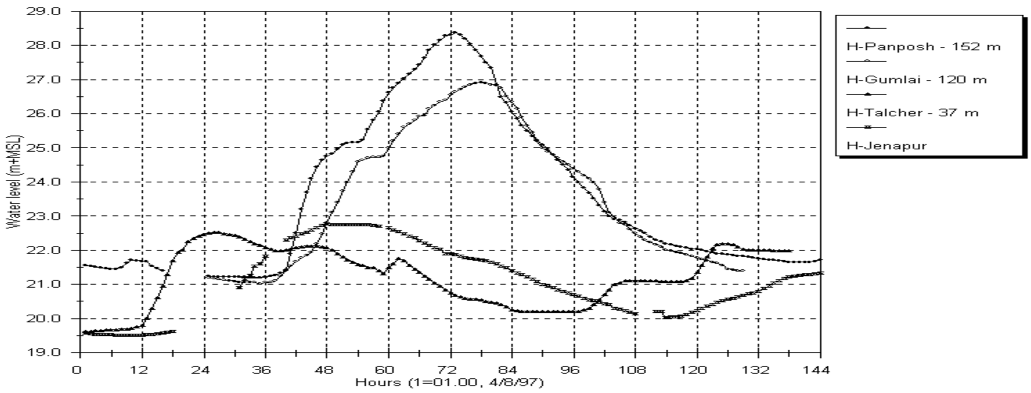



Figure 4.13 River stages along Brahmani river, flood 4-10 August, 1997

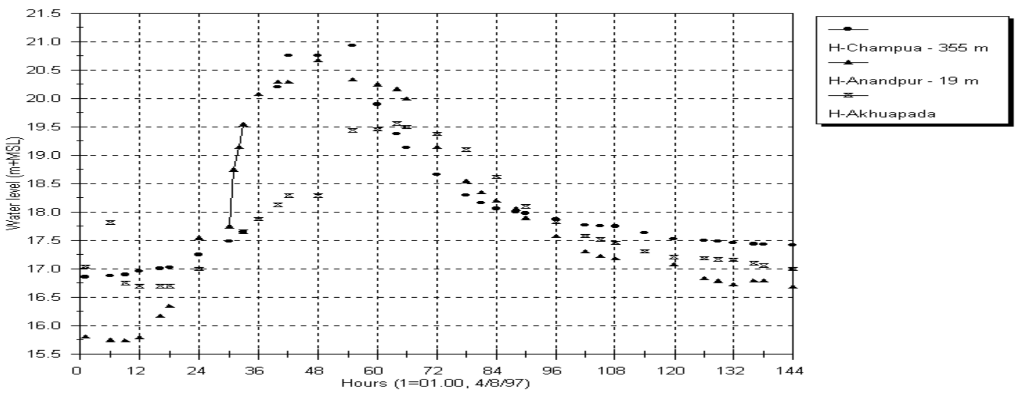



Figure 4.14 River stages along Baitarani river, flood 4-10 August, 1997

**Conclusion**

From the above it is observed that sofar the Rengali reservoir has reduced the historical floods. But particularly when the initial reservoir levels were high, its flood mitigating capacity was not used to its full extent. Improved operation during floods could have reduced damages even further. Such improvements can only be obtained if the lead time of flood forecasts increase. For this forecasts based on rainfall data fed into rainfall-runoff models are required in two steps:

- A first improvement is obtained if use is made of observed rainfall in real-time, and
- A further increase of lead time can be achieved if QPF becomes available.

The importance of the latter is should not be underestimated in view of the travel time between Rengali and Jenapur in relation to the basin lags of Brahmani d/s of Rengali and of Baitarani.

It is also concluded that instead of a phased expansion of the telemetry system as suggested in the SAR (see Chapter 1), a full implementation at one go should be pursued. The benefits of the first phase of the earlier proposed expansion will only be marginal in comparison with the existing system

## 4.3 Proposed flood forecasting system

From the above it follows that to make optimal use of the flood mitigation capacity of Rengali dam one should strive for the maximum possible lead time. A large lead time is also required to inform the population in the flood prone areas well in advance to safeguard property and lifestock. Large lead times require the coverage of the entire Brahmani and Baitarani basins, starting off from real-time rainfall data and quantitative precipitation forecasts.

The forecasting system should therefore consist of the following components:

1. Telemetry system for real-time monitoring of rainfall and river stages covering the entire basins
2. Quantitative precipitation forecasting
3. Hydrologic-hydrodynamic modelling system, and
4. Flood information dissemination.

The layout of the telemetry system is determined by the required input for the modelling system and QPFs, which are described in the following sub-sections. The details of the telemetry system are dealt with in Chapter 5.

## 4.4 Hydrologic-hydrodynamic modelling system

A suitable modelling system for forecasting of floods along the Brahmani and Baitarani rivers and in the river delta should include the following components:

1. Rainfall-runoff models for all sub-basins in the two river basins,
2. Hydrologic river routing model to route sub-basin outflows through those main river sections which are unaffected by backwater,

3. Reservoir routing model to simulate the behaviour of Rengali and future reservoirs while storing and passing floods,
4. Hydrodynamic flow routing model for the delta combined with a GIS, to transform river inflows to the delta and water levels in the river mouths at the Bay of Bengal into river stages in the delta and to demarcate the extent of flooding,
5. Database, and
6. User interface, for data entry, model interaction and control and for visualisation of input and output results.

The above mentioned model components should be incorporated into one system, with flexible exchange of data from one to another.

In all models data assimilation procedures have to be embedded to combine the model results with actual observations for updating of the initial model condition prior to each forecast run.

**Rainfall-runoff model**

The rainfall-runoff models should be of the **regime** type rather than of the event type of models to be able to transform continuously observed rainfall into net rainfall. Hence an explicit soil moisture accounting routine should be incorporated in the model. For the catchment modelling a lumped distributed approach is required with sufficient flexibility to accommodate for any type of basin. In the approach the basins are divided into sub-basins. In a particular sub-basin uniformity with respect to rainfall distribution and drainage characteristics is assumed. Though a detailed study of the rainfall variability and drainage characteristics in the Brahmani and Baitarani basins has not been made yet it is estimated that sub-basin sizes of at maximum 2,000 to 3,000 $km^2$ will be acceptable to cope with the spatial distribution of the rainfall. A possible distribution of the Brahmani basins in sub-basins is presented in Annex 2. Also a distribution for the Baitarani is given there, though it should be noted that for the making of the latter no detailed maps were available and further fine-tuning will be required. The surface runoff component should be based on the Clark or Tc&R model or similar approach, which allows easy accommodation for various catchment shapes and isochrone pattern.

The data assimilation for the rainfall-runoff models should concentrate on the rainfall only as this component is generally by far the most uncertain factor.

The rainfall-runoff models require through the telemetry system real-time information on:

- Sub-basin rainfall, derived from real-time point rainfall data or weather radar data, and
- River flows, derived from real-time river stages and regularly updated discharge rating curves, to update the model state.

From a few locations historical data on climatic variables (sunshine duration, humidity and wind speed) will be required for the computation of potential evapo-transpiration. It is assumed that long term average evapo-transpiration data (varying through the year rather then from year to year) will be appropriate for modelling purposes, though the validity of this statement is yet to be confirmed by studying the variation of the potential evapo-transpiration from year to year.

To get proper data on basin outflows, it is preferable that, in addition to the main stream stations, observation stations are also located on important tributaries to avoid the subtraction of two large figures from main stream stations.

**Hydrologic routing model**

Though various options are available to route sub-basin outflows through the main rivers, in the absence of backwater generally a hydrologic routing method will suffice. For this a two layer Muskingum routing technique or similar, which can deal with different celerities of the flood wave (inbank and overbank flow situations), is required. The advantage of hydrologic routing over hydrodynamic routing methods is its simplicity and speed without much loss of accuracy. Such models are rapidly developed from observed discharge hydrographs for river sections. Alternatively, the model parameters may be derived from the hydraulic characteristics of the river sections using e.g. the Muskingum-Cunge method or are fitted to hydrodynamic model simulations.

It is noted that considerable attention is to be given to validation of river stage and flow data to arrive at a consistent set of data for model calibration and verification.

The model should incorporate a data assimilation procedure to adjust the model state based on observations prior to each forecast run. Hence the model requires real-time information on river flows, derived from real-time river stages and regularly updated discharge rating curves, to update the model state.

**Reservoir routing model**

In the routing model a reservoir component should be incorporated to simulate in detail the behaviour of Rengali dam and reservoir and other reservoirs in the basin (if needed) in response to operation strategies. The model should accommodate for any reservoir storage-elevation curve and discharge-elevation relation. Outflows may be set or derived from gate settings. The model should be able to compute reservoir inflows based on releases and water level variations.

**Hydrodynamic flow routing model**

In the delta the flow pattern becomes complex due to the interaction of various river branches, flood plains and backwater effects. For the delta therefore a hydrologic routing model will not suffice. Therefore, a hydrodynamic flow routing model based on the full Saint-Venant equations for non-uniform unsteady flow has to developed instead, to reliably transform the delta inflow and stages in the Bay of Bengal at the river mouths into water levels in all river branches. Since the flood plain is mainly embanked and divided into compartments a one-dimensional hydrodynamic flow routing model combined with cells for quasi two-dimensional simulation of flood plain inundation will be required for this. The model should be developed based on detailed information about:

- longitudinal and cross-sectional profiles of the river branches and their hydraulic roughness,
- floodplain levels, extent, land use and vegetation,
- detailed information about height and extent of bunds, and
- structures affecting the flow and/or water levels.

Special measuring campaigns will be required to collect data on flow velocities and distribution between the branches for low, medium and high flood conditions for calibration and verification purposes.

The model should be able to visualise the extent of flooding by making use of a GIS of the delta area. When this information is combined with GIS layers on land use and economic activities flood damage can directly be computed and an easy instrument is obtained to further reduce the flood damages by selecting the best storage/release strategy for Rengali dam in combination with temporary measures in the delta.

Note that the hydrodynamic model in combination with the GIS, used in an off-line mode, is also an excellent tool to assist in the design of permanent flood protection measures.

The operation of the hydrodynamic model requires in real-time observations of Brahmani and Baitarani river flows and stages at the delta boundaries (Jenapur, Akhuapada and Bay of Bengal) and at a few locations inside the delta as well as forecasts for the model boundaries.

**Databases**

All relevant static and semi-static data on catchments, rivers, floodplains, reservoirs, structures, stations, land use, population, etc. as well as on historical hydro-meteorological time-series should be stored in the permanent FFS database (Flood Forecasting System database). This database should be updated at regular intervals, say weekly. To this database reporting and graphical tools as well as statistical functions should be linked for preparation of reports and execution of statistical analysis. The stored data should incorporate all the data required for recalibration of the models and to carry out reservoir studies for design of rule curves.

For actual flood forecasting the models will communicate with a dedicated temporary FFS database, which contains the real-time input data (field observations) as well as the model forecasts, required to update the models. Its content should regularly be transferred to the permanent FFS-database.

**User interface**

The availability of an easy to use, menu driven graphical user interface under Windows is crucial for an efficient operation of the Flood Forecasting System. Its functions should include, but not be limited to the following functions:

- communication with the database
- checking of input data
- activating the models as soon as the measurements are entered into the database
- visualisation of the actual situation in the river system on screen
- forecasting of flood flows for arbitrary rainfall forecasts (scenarios), eventually with arbitrary reservoir management strategies
- numerical and graphical output with respect to past, actual and forecasted water levels and flows
- transfer of data from the temporary database to the permanent database
- “maintenance” of models, i.e. adjustment of standard model inputs, as appropriate.

**Model development**

From discussions with the authorities it was learned that a two step approach in the development of the modelling system for flood forecasting is required:

1. Step 1: development of the rainfall-runoff and river routing and reservoir models (including also database and user-interface), which are essential to derive the inflows to the delta area under various reservoir operation strategies. An early development of these components is essential to arrive at short notice at improved reservoir operation strategies to further mitigate the floods and to reduce the risk of overtopping of spillway capacity.
2. Step 2: development of the hydrodynamic model of the delta region to improve and detail the dissemination of flood warnings and to further reduce the economic losses by selection of the most beneficial reservoir operation scenario and temporary measures in the delta.

## 4.5 Real-time rainfall data and Quantitative Precipitation Forecasts

Input of rainfall data to the modelling system comprise of:

1. real-time point rainfall observations
2. real-time sub-basin rainfall from Paradweep Port radar, and
3. Quantitative Precipitation Forecasts.

**Radar based rainfall data**

Radars have been successfully used in estimating rainfall on real time basis. For this purpose, radar echoes are digitised. IMD has installed a 10 cm Cyclone Detecting Radar at Paradweep Port, which has a range of 400 km. It covers the catchment areas of both river Brahmani and Baitarani. To make use of this radar a study has to be conducted to calibrate the radar echoes using the ground truths (short-term rainfall intensities) by installing at a number of locations automatic rain-gauges. Once the radar echoes are digitised, it can be used for operational purposes. There are, of course, a number of difficulties in estimating precipitation at a large distance from the radar. The curvature of the earth results in the beam altitude being quite large, sometime missing low level rain at the extremities of the scan. On the other hand, low elevation scans often encounter problems with ground clutter where the lower part of the beam intersects high structures or hills. Anomalous propagation occurs due to the rate of change of refractive index of the atmosphere with height. Attenuation of the radar signal occurs during heavy and widespread rainfall. Finally, there is the presence of the bright band caused by the melting layer. It is possible to sort out most of these problems and radar can be usefully employed in flood forecasting. Hence, up to a distance of 200 km from Paradweep Port reliable rainfall estimates from the radar can be obtained, particularly when the results are in real time adjusted with point rainfall observations. This implies that the entire Baitarani and the south-eastern part of Brahmani river are within the range of the radar. With this system it is possible to derive automatically for each identified sub-basin the catchment rainfall.

**Quantitative Precipitation Forecasts**

For flood forecasting, the basic input beside real-time rainfall observation is the quantitative precipitation forecast (QPF). The added value of using QPF is the extension of the forecast lead time, which was shown to be of high importance to make use of the flood mitigation capacities of the Rengali reservoir to the full extent.

Rainfall forecasting in India is done by IMD using synoptic – weather maps for surface and upper air using meteorological data of 560 surface and 132 upper air stations on real time basis. In addition, numerical models are also used. For rainfall prediction, a multi-level Primitive Equations Limited Area Model is used for short range predictions in the tropics. The model physics includes boundary layers, dry convection adjustment, deep cumulus convection and large scale condensation. The effect of mountains including Himalayas is incorporated through Sigma Coordinate formulation. The model produced good forecast of pressure, wind and temperature field up to 48 hours, but rainfall prediction to desired accuracy is not yet achieved in tropics. Therefore, at this stage, it may not be possible to prepare QPF for estimating the flood potential accurately.

At present, IMD is issuing semi-QPF. One of the reliable techniques of preparing the semi-QPF is Analogue Method. The procedure is that depressions/cyclonic storms that cause heavy rainfall in the catchment areas of river Brahmani and Baitarani and exhibit similarity in characteristics of some of the past systems are identified. The associated rainfall distribution pattern is then predicted on the basis of the past yields in the catchments. It may be clarified that the rainfall distribution in the catchment depends upon the direction and speed of movement of the system with respect to the orientation of the catchments. Once these past system are catagorised, Analogue maps for each category are prepared for forecasting purposes. This method yields fairly good results provided that the approaching weather system is properly identified.

It is noted that with the help of the Paradweep Port radar and satellite information two potential sources are available to improve on the QPF estimates. With the radar the approaching storms can be quantified and tracks can be visualised within the reach of the radar, whereas the reach can be further extended by making use of satellite images. Hence storms can be identified and to some extent quantified well before they reach the coast of Orissa.

It is therefore of utmost importance that the Flood Forecasting Centre arranges with IMD a formal agreement on the use of the IMD radar at Paradweep port for real-time rainfall estimation and QPF for flood forecasting. This requires:

- Installation of software and hardware at Paradweep Port to translate the radar echoes into sub-basin rainfalls
- Calibration of the weather radar by comparing the radar echoes at locations with the observed point rainfall, and
- Establishment of communication links between the radar tower and Rengali dam.

# 5 Telemetry system

## 5.1 Objectives

To operate the flood forecasting model the following data are required on real-time basis:

- Point rainfall data

- Sub-basin rainfall data from the weather RADAR
- Quantitative precipitation forecasts
- River stages
- Reservoir stages, and
- Reservoir outflows.

The data acquisition interval is 1 hour during floods (to be initiated by IMD at the weather radar tower at Paradweep Port) and 3 hourly during the rest of the monsoon season.

To accomplish the objectives, a telemetry system shall be set up.

## 5.2 Bid requirements

The bid section for the telemetry system shall give a turn-key solution. It shall cover the following:

- all costs for hardware, software, installation, manuals, guidelines and training
- depict the proposed radio communication solution, including all costs required to fully implement the system. The reliability and availability aspects shall also be assessed and presented.
- all recurring costs for licence fees, communication costs, etc.
- annual maintenance costs for the full system

## 5.3 General concept

At each of the identified field stations, a Data Acquisition System (DAS) collects rainfall data and at some stations water level data as well. The DAS comprises a data acquisition segment and a data communication segment. The collected data are transmitted by radio to the Data Processing Centre (DPC) at the Rengali dam. All stations together comprise an integrated data acquisition and telemetry network. A data logger is part of each DAS to record all acquired data for later retrieval.

The stations of the telemetry system for the first stage implementation (i.e. excluding the delta) are listed in Table 5.1. The required additions for the second stage are presented in Table 5.2

Table 5.1: Stations, functions and variables in telemetry network, first stage

| Station | Function | Variables |
|---|---|---|
| Paradweep Port | RRS | R/RR/QPF |
| | | |
| ***Upper Brahmani*** | | |
| Chainpur | DAS | R |
| Raidih | DAS | R/GD |
| Palkot | DAS | R |
| Kurdeg | DAS | R |
| Simdega | DAS | R |
| Bolba | DAS | R/GD |
| Lohardoga | DAS | R |
| Mandar | DAS | R |
| Gumla | DAS | R |
| Bharno | DAS | R |
| NH23-Koel crossing | DAS | R/GD |
| Torpa | DAS | R |
| Sode | DAS | R/GD |
| Gudri | DAS | R/GD |
| Manoharpur | DAS | R/GD |
| Jagannathpur | DAS | R |
| Panposh | DAS | R/GD |
| Gumlai | DAS | R/GD |
| Deogarh | DAS | R |
| Pallahara | DAS | R/GD |
| Rengali | DAS/DPC | R/L/O |
| | | |
| ***Lower Brahmani*** | | |
| Naktiduel | DAS | R |
| Sarapal (Chendipada) | DAS | R/GD |
| Samakoi River | DAS | R/GD |
| Samal | DAS | R/GD |
| Talcher | DAS | R/GD |
| Nigra River | DAS | R/GD |
| Kamakhya Nagar | DAS | R/GD |
| Jenapur | DAS | R/GD |
| | | |
| ***Baitarani*** | | |
| Jharpada | DAS | R/GD |
| Champua | DAS | R/GD |
| Swampatna | DAS | R/GD |
| Anandapur | DAS | R/GD |
| Akhuapada | DAS | R/GD |

Legend: see Table 5.2

Table 5.2 Stations, functions and variables in telemetry network, second stage

| Station | Function | Variables |
|---|---|---|
| Dharmasala | DAS | R/G |
| Indupur | DAS | R/G |
| Aul | DAS | R/G |
| Dhamara | DAS | R/G |

| | |
|---|---|
| DAS | Data Acquisition System |
| DPC | Data Processing Centre |
| RRS | Rain RADAR Station |
| RR | RADAR rainfall |
| R | Rainfall (Tipping Bucket Raingauge) |
| QPF | Quantitative Rainfall Forecast |
| GD | Water level station with discharge rating curve |
| L/O | Reservoir level and reservoir outflow |

### 5.3.1 Radar station

A special position in the network has the Rain Radar Station (RRS) at Paradweep Port. From the radar echo data rainfall is estimated for the sub-basins and transmitted to the DPC. The radar centre also prepares QPFs. The rainfall estimates and QPFs are transmitted to the DPC with the same transmission interval as for the DAS stations.

### 5.3.2 Processing cycle

During floods every hour new data are acquired, transmitted and processed into a new forecast. During the rest of the monsoon season the processing cycle is adjusted to 3 hourly intervals. The radar station at Paradweep Port informs the DPC at Rengali to change the transmission interval from 3 to 1 hour and reverse again after passage of the flood event.

### 5.3.3 Integration

At each station, the data acquisition segment and the data communication segment shall co-operate automatically and in an integrated manner.

At the RRS where the rainfall estimates and QPFs are generated integrated communication facilities shall be established for transfer of the data to the DPC. Further, a simple protocol is required to exchange status messages and request for information between DPC and RRS.

At the field station, the data acquisition segment and the data communication segment shall be compatible with each other. In particular the data exchange between both segments shall be fully compatible, e.g. the communication segment should deal with the interrogation (polling) command from the DPC and request the data acquisition segment to deliver the latest data. The data message from the data acquisition segment should be of a format that the data communication segment can handle. The compatibility also includes aspects such as power supply, housing, interference immunity etc.

### 5.3.4 Reliability

Main use of the telemetry system is acquisition and delivery of water level and meteorological data during bad weather events, i.e. under intense rainfall, heavy wind load and concentrated lightning. During monsoon, the availability and performance of the complete system, also including data delivery within the specified maximum data retrieval duration, shall be 99%. This requirement may affect the choice of communication system.

The projected lifetime of the complete system is 10 years. During the projected lifetime the complete system shall meet the technical specifications and requirements of the Bid Document.

Due to local conditions, maintenance can only be given before and after each monsoon.

## 5.4 Data Processing Centre

The data communication segment at the Data Processing Centre (DPC) consists of a network controller PC and one or more data communication segments. The network controller PC manages the data retrieval processes and transfers the retrieved data to the forecasting model through a local area network.

The number of communications segments/transceivers depends on the capacity of the communication channels and the redundancy required to realise the specified availability and performance.

The DPC shall be provided with redundant UPS capacity (6 hours) and, in combination with generator sets, adequate to sustain operation for at least 72 hours without mains supply.

## 5.5 Data Acquisition System

The Data Acquisition System (DAS) consists of a data acquisition segment and a data communication segment. Both segments make use of the same power supply.

The data acquisition segment comprises the sensors, a data acquisition controller/data logger and an integrated power controller for the sensors. The data communication segment comprises the data communication equipment on site, all intermediate components and the network controller at the DPC. Power supply is based on rechargeable lead batteries, charge controller and power sources like a mains power supply and/or solar panels.

### 5.5.1 Sensors

The choice of water level sensor depends on local conditions. For each station the choice is to be evaluated. At least the following sensor types shall be supported by the data acquisition system: float-counter weight with shaft encoder for stilling well installation and vented gauge pressure sensor for other installations.

In reservoirs a stilling well will be available for installation of a float-counter weight instrument. For pressure sensor stations, the design is of the civil works is to be optimised for the local conditions.

Rainfall is measured by a tipping bucket raingauge. A bucket tip shall be equivalent to 0.2 mm rainfall. The instrument shall have a diameter of 200 mm.

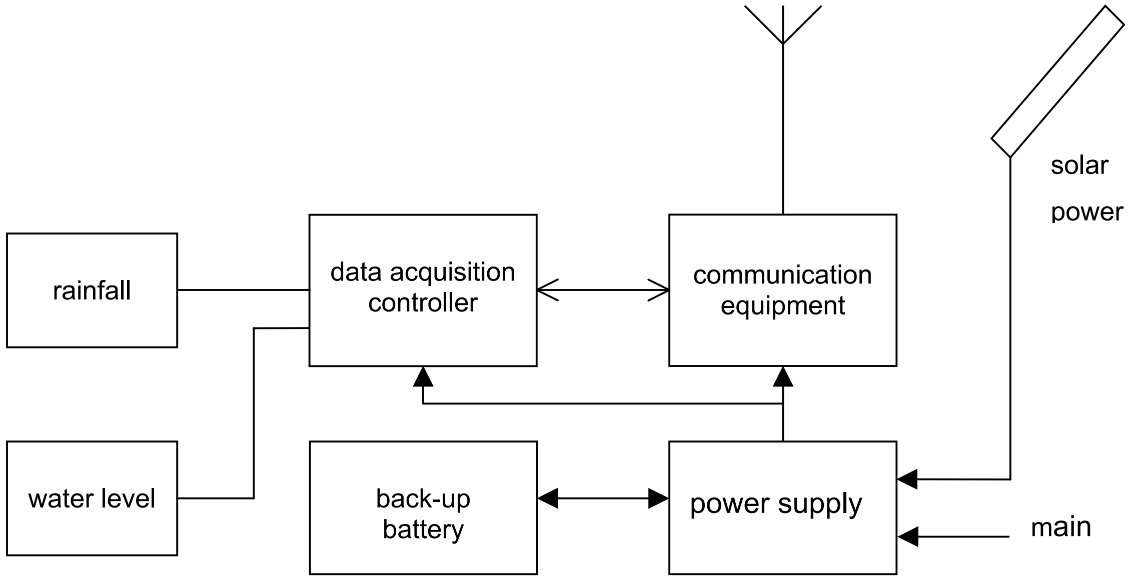



Figure 5.1: Diagram of the DAS field section

### 5.5.2 Accuracy and range

The accuracy and range requirements for the variables are shown in the below. Specifications for the sensors are enclosed in Annexes 3 to 5 of this document.

Table 5.3 Variable requirements

| Variable | Sensor | Accuracy | Range |
|---|---|---|---|
| water level (reservoir) | shaft encoder | 0.005 m | 20 m |
| water level (river) | pressure | 0.01 m | 15 m |
| Rainfall | tipping bucket | 2% of reading | |

Water level measurements shall be filtered to suppress wave effects. For the shaft encoder type water level sensors, a traditional stilling well is required to filter wave effects. Additionally, the data logger may acquire a number of instantaneous water level readings and calculate the average out of these.

For the pressure sensor a similar data acquisition and software averaging process shall be applied to filter out the wave effect. However, as the pressure sensor in most cases will not be installed in a stilling well, a more rigorous wave suppression filter is required. This is accomplished by taking more samples over a longer period.

The sampling interval may be adjustable from 0.5 to 5 seconds, the size of the sampling series for averaging shall be adjustable between 1 and 100 or more. The recorded water level value shall be the average of a completed sampling series only.

The rainfall value is the tip count accumulated over a completed sampling interval. The data of the active/pending sampling interval is not made available for transmission.

At midnight, i.e. 00h00m00s, the data logger commences with a new recording interval. Recording intervals may be selected from the following range: 15 and 30 minutes and 1, 2, 3, 4, 6,12 and 24 hours.

### 5.5.3 Cable length

The length of each sensor cable shall be quite adequate to cover the distance from the sensor to the DAS. The cable length shall be evaluated for each sensor and station. The sensor signal shall be compatible with the required cable length. For all cable lengths accuracy shall be maintained regardless the length of cable.

### 5.5.4 Data logger

The data logger acts as the system controller. It controls the power to the sensors, acquires the sensor signal and prepares the telemetry messages for transmission by the data communication segment.

Another data logger task is to record all acquired data for later retrieval. The data logger shall have sufficient memory capacity to contain combined data of one year of hourly data acquired from a water level sensor and a raingauge.

The data logger shall have an accurate clock for time keeping of its internal processes and for time stamping of the acquired data. The clock shall have an accuracy of 1 minute per month or better.

All volatile data in the data logger, e.g. program settings, data logger program, collected data shall be retained in battery backed memory or in EEPROM (or similar). The clock shall be battery backed. The data logger backup time shall at least be 1 year without external power.

The data logger software shall be Y2K compliant.

### 5.5.5 Data retrieval process

Upon reception of a request for data, the data communication segment reports that request to the data logger. Two types of data requests are supported viz. latest data and data of a date and time as specified by the request. The first type is the standard for normal use. The second type allows for retrieval of missing data, e.g. data that could not be retrieved in a previous session due to a communication failure.

Upon reception of the data request, the data logger retrieves the required data from its memory and assembles the telemetry message.

The telemetry message shall contain:

1. the station/data logger identification code
2. the retrieved sensor data, i.e. rainfall or, depending on the installed instrument package, rainfall and water level
3. the date and time stamps associated with the date and time of acquisition of the retrieved sensor data. The date and time do not point to the date and time retrieval from memory.

### 5.5.6 Data logger Control Unit

For set-up, control, monitoring and data retrieval of the data logger, a Data logger Control Unit (DCU) is required. The DCU may be PC based, e.g. implemented on a palmtop or a laptop PC. It should be portable, handy and lightweight. All cables, interfaces, software and other accessories required for effective operation shall be included in the bid.

The power requirements shall be moderate, the power autonomy on a single battery charge shall be at least 24 hours continuous/aggregated use. In view of the projected lifetime and to accommodate to changing requirements, it shall be easy to update the DCU functionality at the Purchaser's office.

## 5.6 Data Communication System

The radio segment can be terrestrial radio, e.g. HF radio modem, Meteorburst or VHF but also satellite based, e.g. VSAT. The choice out of these communication systems will be based on costs, technical feasibility and guaranteed reliability.

On the cost side both the one time investment costs to build and implement the network as well as the recurrent costs such as annual maintenance, communication licence fees, cost of VSAT access and use shall be made available for evaluation. Further, the costs of operation, service and repair costs will be considered during bid evaluation. The choice will be for the technically feasible and cost effective solution.

The bid shall reveal all the costs item wise. Further, the bid shall give a separate figure for investment cost and the annual recurring cost covering all the stations of the bid. The technical section of the bid shall give a comprehensive description of the proposed data communication system, performance data and a commitment for the reliability and availability for all communication links from DAS/RRS to DPC.

### 5.6.1 General requirements

The telemetry system can be passive; i.e. no provision is required for event reporting by the field stations. The telemetry system shall be simple and cost effective and operation shall be reliable (99% availability).

The telemetry messages from the field stations shall also contain house keeping information of each of the field stations, amongst others the clock reading at the time of transmission, battery voltage and state of battery charging. The house keeping messages may be retrieved from the field stations by a separate command and at a longer interval in between of retrieval of rainfall and water level data.

### 5.6.2 Interface requirements

All data exchange between DAS/RRS and the communication segment shall be digital via standard serial communication such as RS232/422/485. The RRS and DAS shall support the commands and mode of data exchange as required by the communication systems.

### 5.6.3 Radio wave propagation survey

If terrestrial radio is proposed, then a radio wave propagation study shall be part of the bid.

### 5.6.4 Radio frequencies

A list of required radio frequencies and transmitter power, station wise, shall be included with the bid. The Bidder shall ascertain the availability of the proposed radio frequencies for the telemetry application from the regulating agency.

### 5.6.5 Timeliness

The arrival times of the retrieved data at the Data Processing Centre (DPC) are affected by the time and duration of transmission, the data communication protocol, error recovery procedures and the delay at intermediate stations like repeater stations and/or hubs. In order not to hamper the timely execution of the forecasting, the data retrieval process is ceased when the maximum data retrieval duration is reached. Initially, the maximum data retrieval duration is set to 15 minutes. The forecast model is updated with real time data and executed upon reception of the complete data set but not later than the maximum data retrieval duration after the beginning of a processing cycle. If for whatever reason not all data have been received at that time, the model starts anyway.

### 5.6.6 Communication

The telemetry system shall operate in a polling mode, i.e. the DPC shall interrogate all remote stations (DAS) and RRS to transmit the acquired data. The data communication processes, as executed by the communication system, shall implement effective handshaking and error detection/recovery protocols ascertaining error free data delivery.

### 5.6.7 Communication schedule

The communication schedule is controlled by the DPC. The interrogation sequence starts with the most significant DAS and gradually works towards the least significant station. Each DAS gets only a limited data retrieval duration allotted, if it fails to deliver the data within the allotted time, it will be skipped. After completing the full list of stations, the interrogation process is executed again, in the same sequence, but only accessing the skipped stations. The interrogation is ceased when all stations have responded successfully or when the maximum data retrieval time is reached.

### 5.6.8 Data integrity

For all communication a CRC (Cyclic Redundancy Check) based error detection protocol shall be applied. At the receiving end, erroneous messages shall be labelled accordingly. Missing messages shall be reported. As a result, under no condition, the forecasting model shall receive erroneous input.

### 5.6.9 Date handling

All date and time functions of the data communication segment shall be Y2K compliant.

## 5.7 Hardware requirements

The system hardware shall be fully compatible with the environmental and operational conditions as encountered at the field stations, at the RRS and at the data processing centre. All used materials shall be sturdy and durable.

### 5.7.1 Power supply

The DAS shall be operated from DC voltage derived from rechargeable batteries. At field stations where mains power is available, mains will be used as primary power source and batteries as backup. At the other stations, lacking mains supply, power will be derived from solar panels.

A charge controller shall maintain the battery charge protecting the batteries against damage due to over charging and full depletion. Depending on the local power conditions, the charging of the batteries shall be from mains and/or solar panels.

The capacity of the power supply shall be sufficient to maintain the system fully functional for a period of at least 7 days. The recharge time on mains shall be less than 12 hours, on solar panels the recharge time shall be less than 2 days, while the system is in full operation in monsoon mode.

The batteries shall be of a maintenance free lead type. As such batteries may be damaged when fully depleted, the charge controller also should monitor the state of depletion in relation to temperature. In case the batteries are about to be fully depleted, then the load has to be disconnected as a precaution.

### 5.7.2 Enclosures

All hardware in the field shall be protected against ingress of dust, moisture and/or insects and similar in compliance with IP65. Permanently submerged hardware, e.g. the pressure sensor for water level measurement, shall comply with IP68 with depth rating of 50 m.

At the field stations, masonry housing will be available to shelter the data acquisition electronics, the radio/modem and the power supply. The Purchaser will make available adequate housing. At some stations, space can be made available in an existing building, at others housing will be constructed. The Bidder shall specify the space and ventilation requirements for the housing in his bid.

Some of the field stations may be inundated during severe floods. The hardware must be adequately protected to remain fully operational.

### 5.7.3 Environment

All hardware shall fully meet the operational and accuracy specifications over the temperature range of 10 to 60ºC and humidity range of 0 to 100%.

### 5.7.4 Cables

All cables shall be of a sturdy type and capable to withstand permanent exposure to the environment of operation, e.g. under water, dug into the ground, tied along an antenna mast. The cable jackets shall be sufficiently UV and chemical resistant to maintain the protection function for at least 10 years.

The antenna cable and related cable connectors shall be of a low loss type for the frequency used. The impedance shall match the radio requirements. Further, cable and connectors shall comply with IP65 specification. Exposed metal parts shall be corrosion proof.

### 5.7.5 Antenna's

The antennas shall be sturdy and rigid enough to sustain operations under all weather conditions. Exposed metal parts shall be corrosion proof.

### 5.7.6 Lightning protection

Each station shall be adequately protected against damage due to the indirect effect of lightning strikes, e.g. by a system of lightning rods. Effective measures shall be included to discharge lightning induced current. The system components, such as sensor, data logger, power controller and radio segment shall be properly shielded and electrically protected against over voltage, static discharge and surges. Moreover, special and well designed protection measures shall be added to electrical components that are connected to (long) cables, e.g. to sensors, solar panels, antenna's and the associated electronics.

To further protect the systems, an adequately designed system of lightning rods shall be included in the civil works of each field station.

### 5.7.7 Safety

The Purchaser will take proper measures to protect the field stations against vandalism and theft. In particular the solar panels, sensor(s), antenna's and connection cables are vulnerable. A fence may protect the field stations. At some field stations a guardsman may be required.

## 5.8 Training

The purchasers staff shall be trained to effectively operate the system. Proper manuals, guidelines and training documents for all levels of operation and troubleshooting shall be made available upon commissioning of the DAS.

## 5.9 Maintenance

The Supplier shall properly maintain all hardware and software for the duration of the warranty period and thereafter for the duration of the maintenance contract. The maintenance shall ensure continuous and timely delivery at the DPC of accurate and reliable data pertaining from all DAS and the RRS.

In the month before the maintenance contract expires, the proper condition of the hardware and the software shall be demonstrated to the full satisfaction of the Purchaser. Deficiencies have to be remedied immediately by the Supplier, but not later than one month after the maintenance contract expires. The hardware and software shall be in such a condition that they can deliver the required accuracy and reliability for the remaining projected lifetime.

The Supplier shall affiliate with a local firm of adequate capabilities to service and maintain the DAS.

There shall be no need for any of the DAS components to be sent abroad for maintenance and/or repair.

### 5.9.1 Spares

Adequate numbers of spares for continuous and operational use for the duration of the projected lifetime shall be available with the Supplier in India.

# 6 Development of forecasting system

In short, to develop the flood forecasting system the following main steps have to be taken into consideration.

For stage 1 of the Flood Forecasting System (FFS):

1. Elaboration of formal agreement with IMD on active role in flood forecasting and use of Paradweep Port radar and satellite data
2. Procurement and implementation of telemetry system for the first stage in line with the recommendations in Chapter 5.
3. Development of databases for model design, flood damage assessment and planning (see also Annex 1)
4. Development of rainfall-runoff, river and reservoir routing models including calibration and verification
5. Development of a user-friendly menu driven user-interface for the FFS
6. Simulation of real-time forecasting conditions for specific historical flood events and testing the performance of the system
7. Testing of the FFS under actual flood conditions

8. Development of flood warning dissemination procedures and testing of its effectiveness
9. Training of staff in all aspects of modelling, data processing, real-time flood forecasting and dissemination of flood warnings
10. Development of an efficient maintenance system for all components of the FFS.

In addition to the above reservoir operation strategies for all purposes of the Rengali dam have to reviewed, including water use for irrigation and hydropower generation and flood mitigation.

For stage 2 of the Flood Forecasting System activities will include:

1. Extension of the telemetry system to the Brahmani delta
2. Field measurements for the development of a hydro-dynamic model for the delta including bathymetric and hydrometric surveys, flood plain mapping, etc.
3. Actual development of the hydro-dynamic model for the delta, including calibration and model verification
4. Development of relevant GIS layers for the delta region (see Chapter 4)
5. Incorporation of the hydro-dynamic model and GIS in the FFS
6. Testing of the FFS under actual flood conditions, and
7. Training of staff in all aspects of modelling.

It is essential that the State authorities work closely together with CWC and IMD in the development and operation of the Flood Forecasting System, making use to the full extent of all information, knowledge and authority available. Arrangements should be made with the authorities in Bihar to establish part of the telemetry system in the upper region of the Brahmani basin.

**Annex 1**

## Report on field visit to study area

### Introduction

As per the Staff Appraisal Report of the HP:

- Study are to be undertaken leading to the development of a flood forecasting system for Brahmani and Baitarani rivers using catchment modelling techniques. Historical data on rainfall and flows are to be used in its development
- The developed and validated model as a result of the study shall be used to determine locations for communication system that will be financed under HP, for appropriate operation of facilities viz. Rengali dam, Samal Barrage etc.
- For the study and Consultancy RS. 10 million ( 1 US $= 39.8 Rupees) are provided in the SAR

### Outcome First Day

A visit by a team has been undertaken starting 23.06.98 to the basin and the facilities existing therein. The team reached Samal Barrage on Brahmani on 23.06.98. The team consisted of M/s H J M Ogink, Y V Dharma Rao, Dr. G N Padhi, (Consultants) and D P Rath, (Chief Engineer HP, Orissa)

### Outcome Second Day

The team members discussed amongst themselves and Sri M. Das, Chief Engineer Rengali Dam in the morning. During discussions they were also joined by M/s Sri S. C. Mishra, SE and J. Baral, EE in Charge of the Dam. It was indicated that incoming flows during the flood season are intimated by wireless from CWC station at Panposh. This is the only advance information available on impinging floods. The vulnerable area lies in the Brahmani delta below Jenapur. In addition to releases from Rengali dam via Samal Barrage, flows of a Mahanadi deltaic Channel 'Birupa' also flow into the delta. But this channel separates at the 'Naraj' Barrage on Mahanadi and its flows can be prevented from entering Brahmani delta in flood time. A channel called 'Budha' from 'Baitarni' river flowing North of this area and going east also contributes flood flows to the Brahmani delta. There are no control storages on Baitarni River and occurrence of natural flood peaks is important for distress alleviation. Bunching of hydrograph peak of Baitarni and releases from Brahmani has to be avoided by judicious operation.

The delta area is embanked partly. Bathymetric surveys of delta channels, level control for surveys, and tidal level observations at the Brahmani river mouth at its join into the sea are required. These have to be organised under HP by the Govt of Orissa through its agencies. Areal photography or satellite imagery and its analysis for flood events is necessary in modelling to convert flood flows into water levels in the delta and thus its damage potential.

The Samal Barrage located 140 kms upstream of Jenapur is important for alerting the passage of a major flood flow. A DWLR or float type AWLR with shaft encoder can be installed in its pond U/S of the pier extension. Staff gauges downstream can be installed. There is a bridge 18 km downstream on National Highway 23 and a DWLR can be installed there under the HP.

Continuous level data downstream can be obtained by suitable correlation. This is needed to assess whether free or submerged flow is taking placed at the Barrage and to calculate passing discharge correctly.

The team on the way from Samal to Rengali passed the tributary ‘Samakoi’ as it is joining the barrage pond. A HP funded GD station is being set-up upstream of this point covering an upstream catchment of 785 $km^2$.

On ‘Rengali’ Dam there is a gauge well from where reservoir levels are currently being read at 2 hour intervals during floods. Copy of an area and reservoir capacity versus reservoir level curve, available with the EE in charge of Dam operation, has to be collected.

Currently an account of storage change on account of level change is used together with spillway releases and powerhouse releases (based on power generated, tail-water level, net head) is used for estimating inflows into the reservoir. This exercise is being done from 1984-85 from which time the project is operational.

The CWC unit is linked through wireless (HF) with Panposh site, Bhubaneswar office, and Jenapur site. Apparently, hourly rainfall values at Panposh, and hourly water levels can be obtained here. The CWC official is apparently not equipped with wherewithal to issue inflow forecasts and throw light on inflow hydrographs and volumes that can impinge on the Dam. The lead-time from Panposh to Rengali is probably 15 hours and needs an assessment. The ARG at Panposh is not functioning and needs immediate rectification.

Flows of Sankh and Koel rivers upstream of Panposh need modelling. This can be done with CWC involvement as they have stations upstream. The catchment area is 19,000 $km^2$ upto Panposh. Between Panposh and the Dam a number of tributaries a.o. Cohira (CA=1,052 km2) and Mankada ( CA=912 km2) are joining the Brahmani. Their flows need to be modelled.

Salient features of Samal Barrage and Rengali Dam, locally available have been collected, but design studies on Probable Maximum Flood (PMF) for dam and Standard Project Flood for the Barrage and working tables (simulation of power and irrigation releases during operation – studies, now under revision) need to be collected from Bhubaneswar.

**Outcome third Day**

On this day the catchment upstream of Rengali dam was to be visited. The tour started at 07.30 hours and the Rengali reservoir crossing by NH 23 was seen. The reservoir water extended up to this point, resulting in a new and wider bridge on the highway. At some distance from the bridge the GD site of CWC ‘Gumlai’ is located. Currently, there is no wireless linkage here, and this site has no real-time operational role. It is a bridge and boat site for discharge measurement. The data here can be used for a check in between ‘Panposh’ and Rengali dam. CWC is building residences and thus this site will remain.

The Panposh site on Brahmani of CWC was reached at 15.00 hours. This is almost located at the entry point of Brahmani into Orissa. It is 260 km from river origin. Catchment covered upto this point is over 19,000 $km^2$. The river upstream consists of two branches the Sankh and the Koel flowing in the state of Bihar and to smaller extent in Madhya Pradesh. This CWC site is located on land taken on lease and is cramped due to shortage of space. The gauge posts are difficult to approach. They also appeared to need refixing as the bank is loose and varying types of gauge plates do not make it easy for reading the gauge. This station needs upgrading and attention. The ARG is working tough the initial time setting while fixing the chart was more than 15 minutes out.

To appropriately set-up a model both data availability in the area needs to be inventoried. A view has to be taken on their use initially in model calibration and later in running the model for inflow forecasting.

The team returned to Samal Barrage later in the evening and rounded the discussions with project CE and other officials.

**Outcome Fourth Day**

The team returned to Bhubaneswar inspecting the CWC GD site on Brahmani at Talcher and a proposed location for a GD site on tributarry 'Lingrai' under HP.

Talcher GD site : As this site is below the (dam and) barrage, its role in establishing forecasting scenario is nil to marginal. Its historic data can be used in the pre and post project situations. The river gauges as painted on bridge piers are difficult to read in daylight.

'Lingrai site' on NH 42 : during the visit this site was seen to be affected by Brahmani backwaters. The best solution would be to shift the site some 5 km upstream and have bank a operated cable-way for measuring the discharge. Gauges/DWLR shaft encoder type can be established nearby, for operational convenience.

The team returned to SMC's office in the afternoon of 26th and continued with report work and also prepared points for the wrap-up meeting the next day.

**Outcome 5th Day – Wrap-up**

The wrap-up meeting was arranged in the room of CE hydrology, Govt of Orissa at 10.30 hours. Sri Singh Samanta SE, Planning, Sri Sinha, SE, hydrological Observations, CWC, Bhubaneswar and the expert team attended the meeting from Consultants site. CE Hydrology, GOO, conducted the Meeting**.**

Points discussed in the meeting on Study pertaining to Rengali Operation for flood mitigation in Brahmani Basin under Hydrology Project included:

**1. Inventory of topography data**

- 1 in 2,50,000 RF Maps original covering Brahmani & Baitarni Basins, to be listed & acquired
- 1 in 50,000 RF Maps original covering Brahmani & Baitarni Basins, to be listed & acquired
- Marking catchment boundaries of all tributaries and main stem of rivers
- Calculation of channel lengths, catchment areas in both basins
- Drawing line diagrams indicating joining points of tributaries from origin to Jenapur on Brahmani and to Akhuapada on Baitarani

2. **Meteorological station locations**

- Station lists available for Orissa for SRG's
- Station lists relevant in Bihar and MP to be collected
- Verification to be hastened for these two basins
- ARG/s locations, FCS locations, IMD existing station locations in these basins to be marked

3. **GD station data**

- Inventory of CWC/state stations in these basins
- Inventory of long-term continuous flow data, and isolation of periods for floods and data on hydrographs
- Data entry to be carried out through DES
- Hastening in the setting up of stations relevant under Hydrology Project

4. **Data necessary for planning**

- All project data of Samal Barrage and Rengali Dam, such as PMF, SPF studies, return period flood hydrographs (100-50 yr floods)
- Damage centre identification and damage statistics relevant for flood mitigation

5. **Further topographic, hydraulic data and functioning of cyclone Radar for delta areas**

- Identify boats and outboard engines, echo-sounders and crews for bathymetric surveys
- Identify channel stretches where survey is needed
- Purchase a DGPS under HP for level and bathymetry survey
- Satellite monitoring of Cyclones along Orissa coast and Warning capability status
- Damage statistics and centre coverage and setting any level stations and campaign surveys
- Obtaining satellite imagery of high floods in delta areas and damage locations for study

6. **External Consultants inputs**

- Study assembled data and validation of input data
- Model calibration after model setting up for river flows in floods, for Delta levels for various floods, out-fall levels of sea
- Simulation models for operation simulation for water use - for power and Irrigation needs
- Flood mitigation scenarios
- Model efficiencies

## 7. Model efficiencies and transfers to site offices

- Determination of locations from where data is needed to update the state of the forecast model
- Type of communication linkages and quantity determination (Preliminary)

During the meeting, CE Hydrology, GOO wanted that the Operation part to be taken up with priority, based on some targeted maximum flows tolerable at Jenapur and Jajpur. They will also indicate the lag-time needed at these places, for giving forecast. On these the study initially can be based. CWC was to co-operate for providing information in catchment areas in Bihar and MP and participate in the study. With these and with thanks to all that made this visit possible the meeting ended.

**Annex 2**

## Development of preliminary rainfall-runoff model

To get a first estimate about the contributions of the various sub-basins and of lead times to ease the discussions about the forecasting options for the Brahmani and Baitarani rivers a simple rainfall-runoff model has been developed for the two basins based on a lumped-distributed approach. The models consist of the following elements:

1. Rainfall-runoff models for sub-catchments, interconnected by
2. Routing elements for the main rivers.

The structure of the models for the two basins is shown in Figures A.1 and A.2. The assumed catchment areas and lengths and branch length of the routing elements are summarised in Tables A1 and A2.

### Data sources

The basin areas and river lengths for Brahmani basin were estimated from a 1:250,000 scale basin map. Since no accurate data were available on altitudes, the travel and concentration times were extrapolated from data provided by CWC on travel times downstream of Panposh, see Table A3.

| River | Reach | Travel time (hrs) |
|---|---|---|
| Brahmani | Panposh – Rengali | 13* -15 |
| | Panposh – Gumlai | 5* |
| | Rengali – Talcher | 3 |
| | Talcher – Jenapur | 16 –18 |
| Baitarani | Champua – Swampatna | 4 – 5 |
| | Swampatna – Anandapur | 7 |
| | Anandapur – Akhuapada | 12 |

Source: CWC and Consultant (*)

Table A3 Travel times along Brahmani and Baitarani rivers

Upstream of Panposh celerities of 12 to 15 km/hr were assumed (i.e. $v_{max}$ ranging from 2.0 to 2.5 m/s), gradually decreasing to about 7 km/hr in the lowest reaches. Similarly, the characteristics for the Baitarani rivers were derived from data presented in the Baitarani River Basin Planning Report as well as from CWC data on travel times, see also Table A3.

### Rainfall-runoff models

For the sub-catchments unit hydrographs have been derived based on Clark's method. The method involves the construction of a time-area diagram, which is subsequently routed through a linear reservoir. The time-area diagram follows from an analysis of travel times in the catchment. Areas between successive isochrones create the time-area diagram. The time-base of the diagram is the concentration time (Tc), which is the time it takes for the rainfall at the most remote location to be felt at the basin outlet. Since insufficient information about altitudes was available from the available maps, celerities conformable to the nearby main streams were assumed to arrive at values for Tc. In the absence of isochrones, the hourly time-area ordinates were derived from the fractional cumulative areas calculated by the following empirical relations (ACE, 1987):

$A_{cum,i} = 1.414x(T_i/T_c)^{1.5}$ for $0 \leq T_i/T_c \leq 0.5$

$A_{cum,i} = 1\text{-}1.414x(1\text{-}T_i/T_c)^{1.5}$ for $0.5 \leq T_i/T_c \leq 1$

The basin storage factors R in the linear reservoir routing were estimated equal to Tc, conformable to the first estimate for R usually made:

$R/(T_c + R) = 0.5$.

**Routing elements**

For the river routing use was made of the Muskingum method , which is governed by a relation between the storage in a river reach (S) and the inflow (I) to and outflow (O) from the reach:

$S = K(xI+(1-x)O)$

which includes two parameters:

- travel time K, and
- weighting factor *x*.

The latter factor, *x*, was set equal to 0.5, which means that only translation was considered in the river routing, thereby neglecting attenuation. The values for K were derived and extrapolated from Table A3.

**Hydrographs**

With the above described model one-hour Unit Hydrographs (UH-1) were derived for the various sub-basins, i.e. the runoff at the sub-basin outlet due to a net rainfall amount of 10 mm during one hour. The sub-basin outflows were subsequently routed to:

- Rengali reservoir for the Brahmani basin area controlled by the dam
- Jenapur, receiving the Brahmani inflow to the delta, and
- Akhuapada, receiving the Baitarani inflow to the delta.

The UH-1 at Rengali as composed of the contributions from Koel, Sankh and Brahmani rivers is shown in Figure A3. The Figure clearly shows that the major contribution stems from the basin area upstream of Panposh, which can be estimated well in advance (with lead times of one day and more). The contributions of the individual sub-basins in the Koel and Sankh river basins to the flow at Rengali are shown in the Figures A4 and A5. The Figures show that the individual contributions are all of the same order of magnitude, which indicates that the assumed segmentation was well chosen.

The UH-1 of Brahmani river at Jenapur, where the river enters the delta, is shown in Figure A6. It shows a double peaked hydrograph, with the main peak caused by the net rainfall catched in the areas upstream of Rengali or better upstream of Panposh as shown in Figure A7. The figures show that outflows from Rengali are felt at Jenapur some 20 hours later, whereas the basin upstream of Panposh contributes to the flow at Jenapur 33 to 35 hours later. The contribution of the catchment area in between Rengali and Jenapur with its major tributaries is shown in Figure A8.

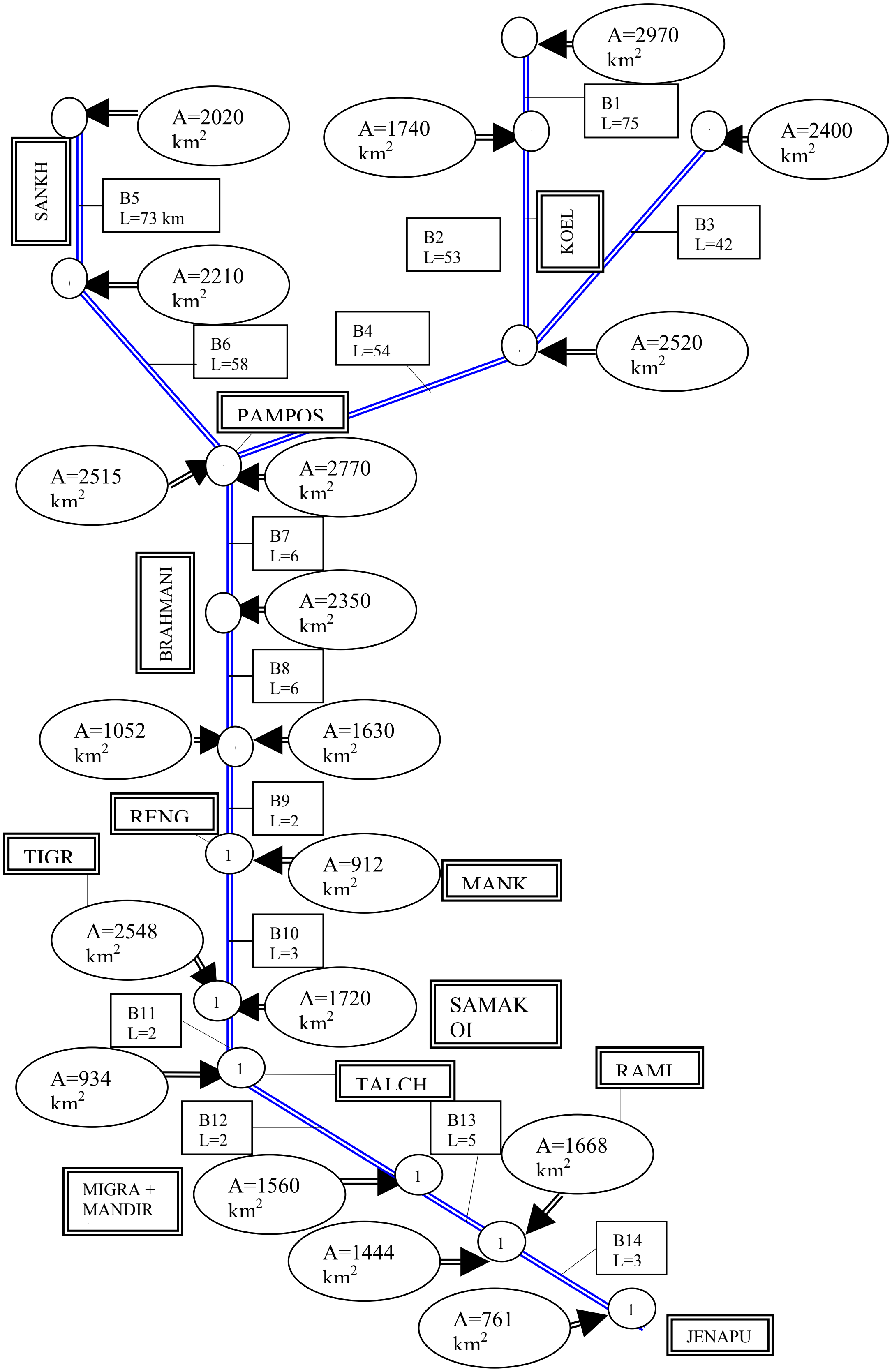
The UH-1 from Baitarani river basin is presented in Figure A9, together with the Unit Hydrograph from Brahmani river basin, assuming that the two basins receive the 10 mm net rainfall at the same time. It is observed that the UH-1 from Baitarani river basin is fairly flat and the lag-time between rainfall and runoff is about 32 hours. Its occurrence coincides more or less with the runoff from Brahmani basin below Rengali dam. The combined runoff due to a uniformly spread 10 mm net rainfall to the delta is shown in Figure A10. It is observed that the uncontrolled part (Brahmani d/s Rengali + Baitarani) peaks at about 24 hours after the occurrence of the rain. Since the travel time from Rengali reservoir to the delta is about 20 hours it implies that from actual rainfall observations very little time is left for pre-releases from Rengali reservoir to create extra storage in the reservoir to mitigate floods. Therefore, Quantitative Precipitation Forecasts by using the rainfall radar at Paradweep to create an extra 12 hour lead time, is of utmost importance for flood mitigation practices when the reservoir levels are already high (September/October).

| Node | Name | Basin | Area | L | Tc | Branch | River | L | K |
|---|---|---|---|---|---|---|---|---|---|
| Nr | | | Km2 | km | Hour | Nr (fr-to) | | km | hour |
| 1 | Midway | Koel | 2,970 | 115 | 8 | | | | |
| | | | | | | 1 (1-2) | Koel | 75 | 5 |
| 2 | Sode | Koel | 1,740 | 80 | 5 | | | | |
| | | | | | | 2 (2-4) | Koel | 53 | 4 |
| 3 | Gudri | Karo R | 2,400 | 105 | 7 | | | | |
| | | | | | | 3 (3-4) | Karo R-Koel | 42 | 3 |
| 4 | Manoharpur | Karo N | 2,520 | 114 | 8 | | | | |
| | | | | | | 4 (4-7) | Koel | 54 | 4 |
| 5 | Raidih | Sankh | 2,020 | 90 | 6 | | | | |
| | | | | | | 5 (5-6) | Sankh | 73 | 5 |
| 6 | Bolba | Sankh | 2,210 | 82 | 6 | | | | |
| | | | | | | 6 (6-7) | Sankh | 58 | 4 |
| 7 | Panposh | Sankh | 2,515 | 85 | 6 | | | | |
| | Panposh | Koel – Deo N | 2,770 | 100 | 7 | | | | |
| | | | | | | 7 (7-8) | Brahmani | 60 | 5 |
| 8 | Gumlai | Lateral | 2,350 | 75 | 6 | | | | |
| | | | | | | 8 (8-9) | Brahmani | 68 | 6 |
| 9 | Cohira-Brah | Cohira N | 1,052 | 65 | 6 | | | | |
| | Cohira-Brah | Lateral | 1,630 | 70 | 6 | | | | |
| | | | | | | 9 (9-10) | Brahmani | 20 | 2 |
| 10 | Rengali | Mankara N | 912 | 65 | 6 | | | | |
| | | | | | | 10 (10-11) | Brahmani | 30 | 2 |
| 11 | Tigra-Brah | Tigra | 2,548 | 105 | 9 | | | | |
| | Tigra-Brah | Lat & Samakoi | 1,720 | 85 | 7 | | | | |
| | | | | | | 11 (11-12) | Brahmani | 28 | 2 |
| 12 | Talcher | Lateral | 934 | 70 | 6 | | | | |
| | | | | | | 12 (12-13) | Brahmani | 20 | 3 |
| 13 | Nigra-Brah | Nigra&Nandira | 1,560 | 65 | 6 | | | | |
| | | | | | | 13 (13-14) | Brahmani | 50 | 8 |
| 14 | Ramia-Brah | Lateral | 1,444 | 75 | 7 | | | | |
| | Ramia-Brah | Ramiala | 1,668 | 77 | 8 | | | | |
| | | | | | | 14(14-15) | Brahmani | 38 | 5 |
| 15 | Jenapur | Lateral | 761 | 48 | 5 | | | | |
| | | | Sum 35,724 | | | | | | |

Table A1 Estimated sub-catchment and river characteristics for Brahmani river basin

| Node | Name | Basin | Area | L | Tc | Branch | River | L | K |
|---|---|---|---|---|---|---|---|---|---|
| Nr | | | km2 | km | Hour | Nr (fr-to) | | km | Hour |
| 1 | B1 | Baitarani | 2,000 | 120 | 9 | | | | |
| | | | | | | 1 (1-2) | Baitarani | 65 | 6 |
| 2 | Champua | Baitarani lateral | 2,792 | 100 | 9 | | | | |
| | | | | | | 2 (2-3) | Baitarani | 50 | 6 |
| 3 | B3 | Baitarani lateral | 2,333 | 100 | 9 | | | | |
| | | | | | | 3 (3-4) | Baitarani | 45 | 5 |
| 4 | Anandapua | Baitarani lateral | 2,000 | 100 | 9 | | | | |
| | | | | | | 4 (4-5) | Baitarani | 45 | 6 |
| 5 | B5 | Baitarani lateral | 2,000 | 100 | 9 | | | | |
| | | | | | | 5 (5-6) | Baitarani | 45 | 6 |
| 6 | Akhuapada | Baitarani lateral | 2,093 | 100 | 9 | | | | |
| | | (exclusive of south-eastern part) | Total Area 13,218 | | | | | | |

Table A2 Estimated sub-catchment and river characteristics for Baitarani river basin




Model structure Brahmani Rainfall-runoff model

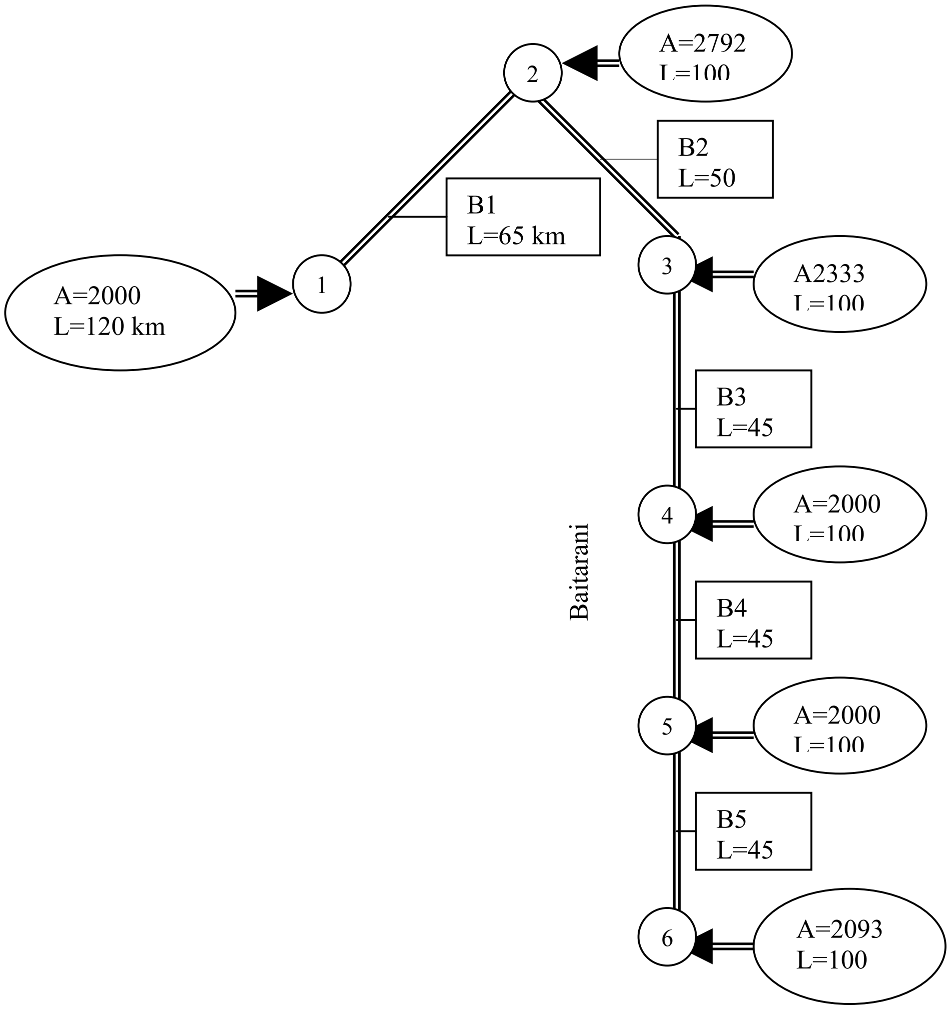



Figure A2 Model structure Baitarani rainfall-runoff model

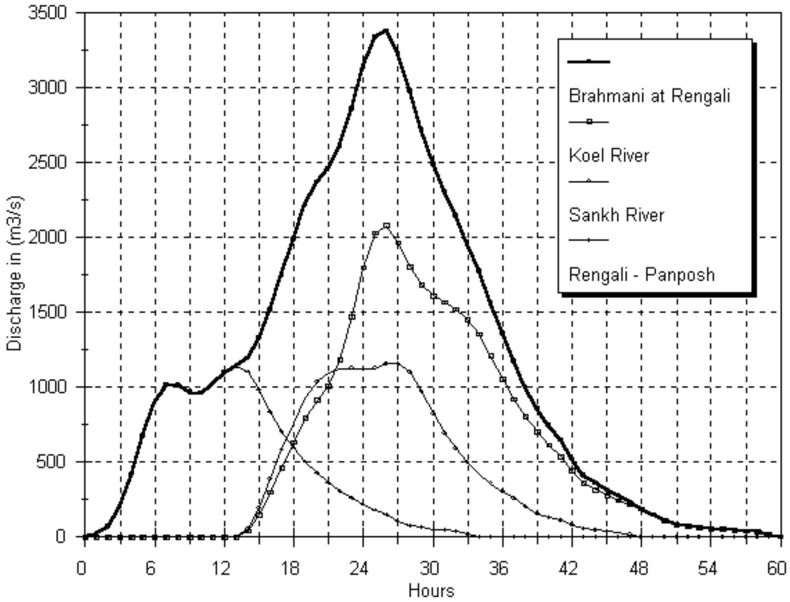



Figure A3 Unit Hydrograph of Brahmani basin at Rengali ($P_{eff}$ = 10 mm)

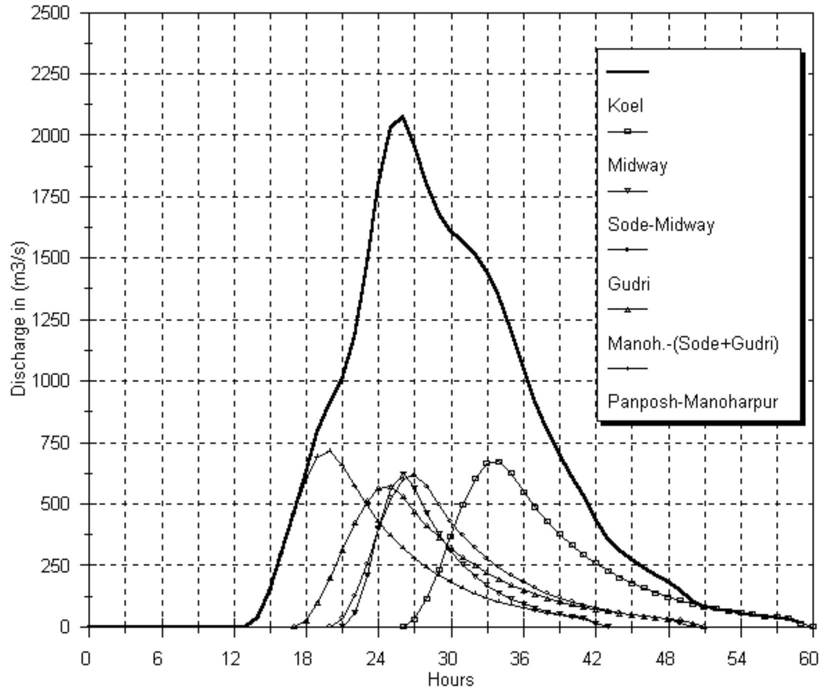



Figure A4 Unit Hydrograph of Koel basin at Rengali ($P_{eff}$ = 10 mm)

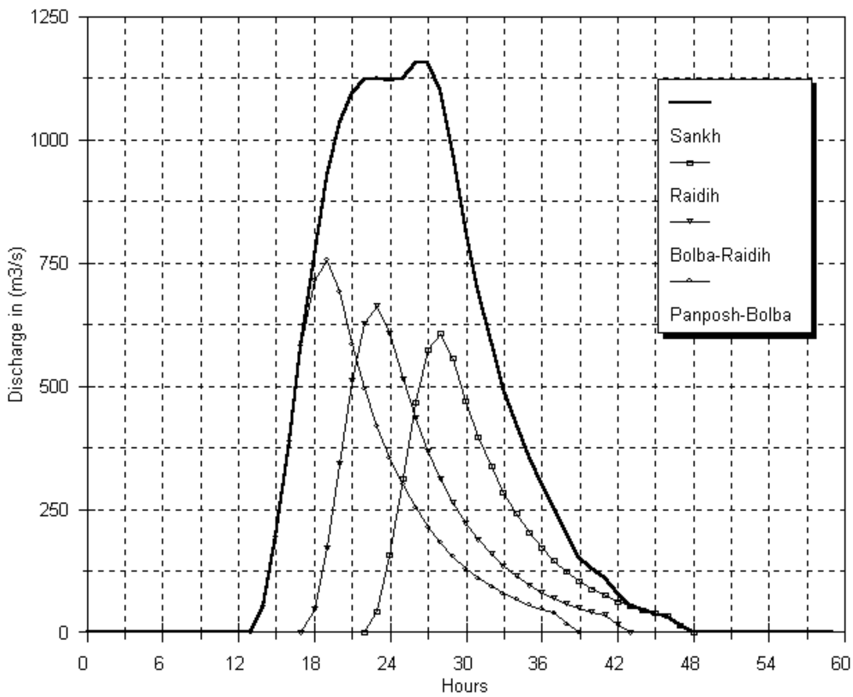



Figure A5 Unit Hydrograph of Senkh basin at Rengali ($P_{eff}$ = 10 mm)

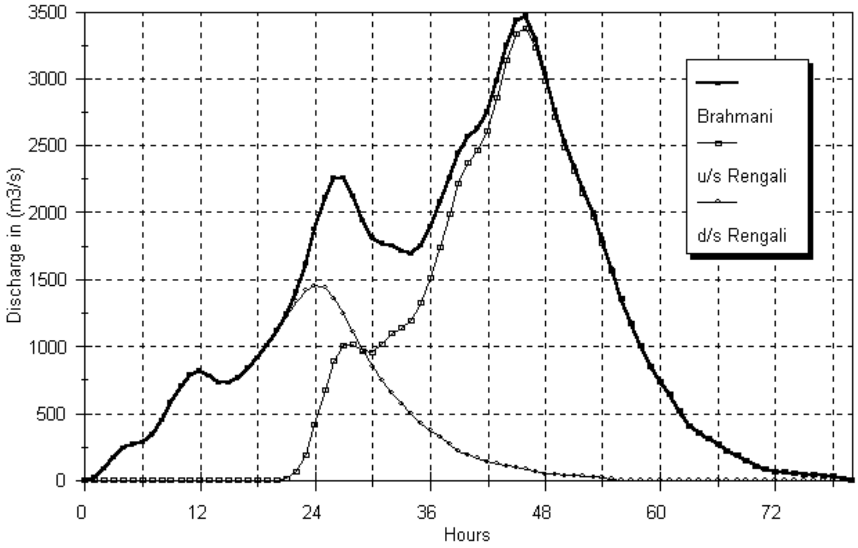



Figure A6 Unit Hydrograph of Brahmani basin at Jenapur ($P_{eff}$ = 10 mm)

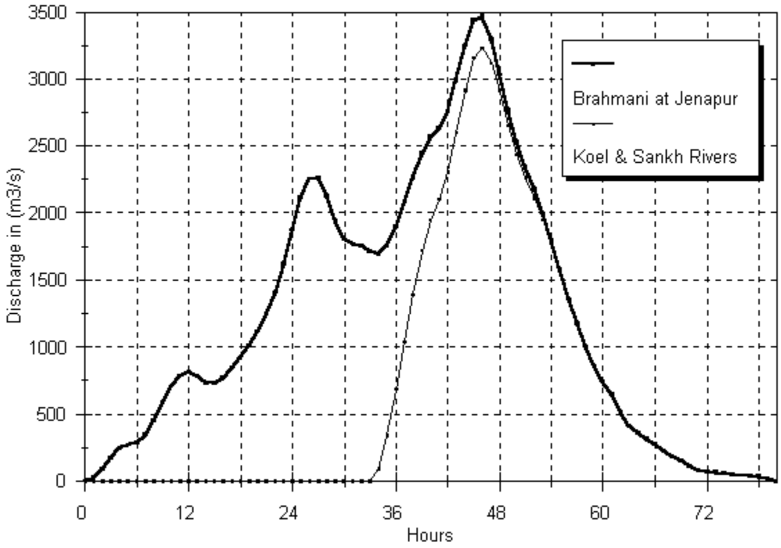



Figure A7 Contribution of Koel and Sankh runoff to Unit Hydrograph of Brahmani basin at Jenapur ($P_{eff}$ = 10 mm)

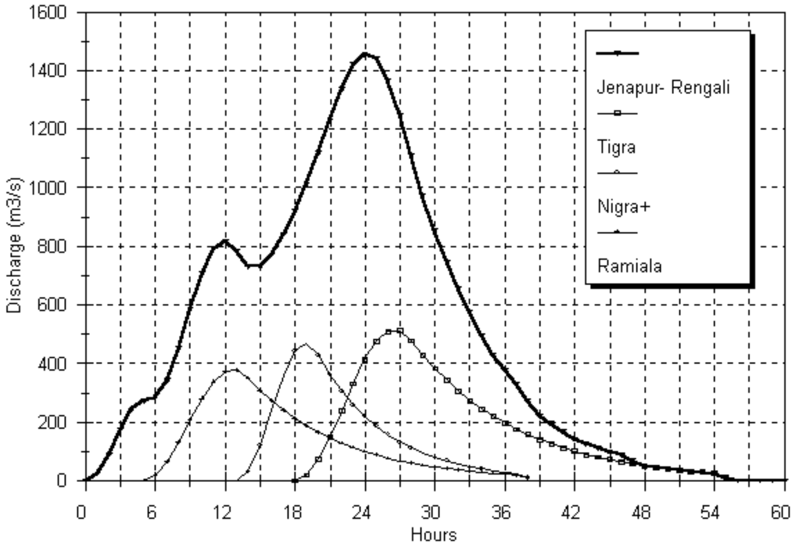



Figure A8 Unit Hydrograph of Brahmani basin d/s of Rengali dam at Jenapur ($P_{eff}$ = 10 mm)

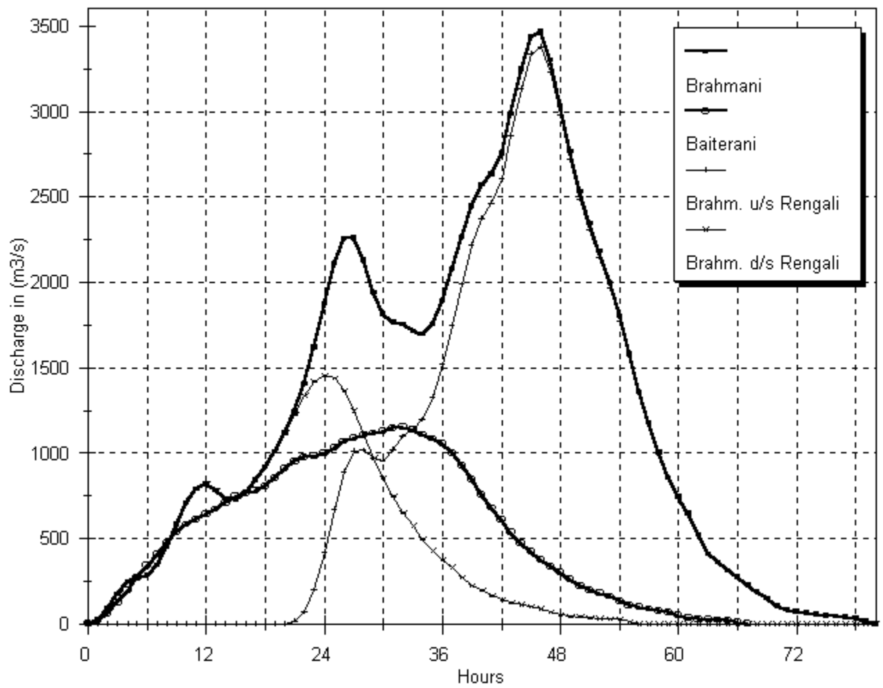



Figure A9 Unit Hydrograph of Brahmani and Baitarani basins at respectively Jenapur and Akhuapada, i.e. delta inflow ($P_{eff}$ = 10 mm)

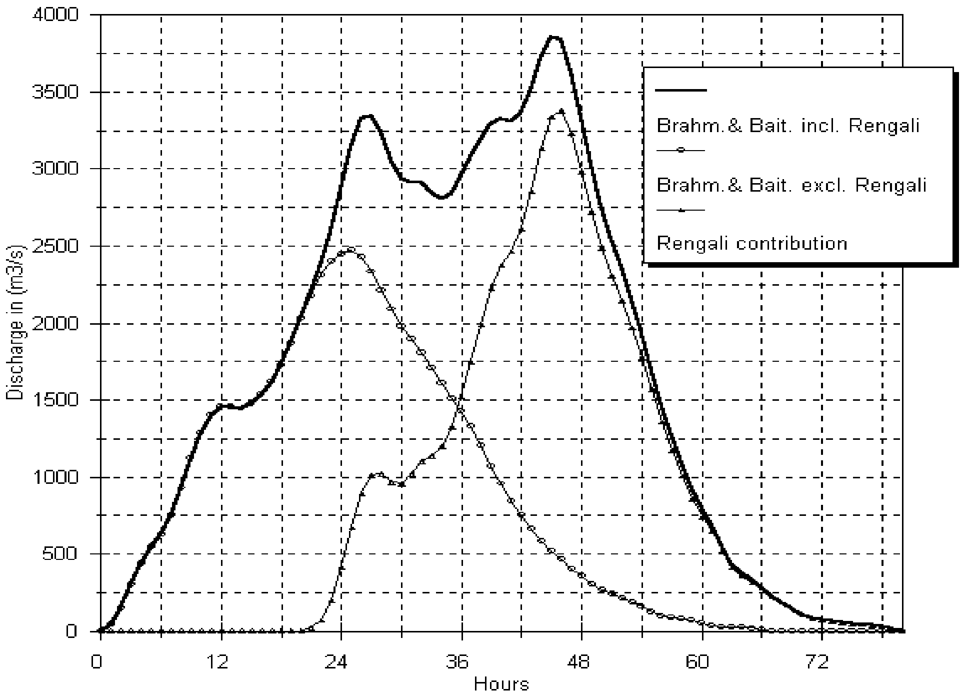



Figure A10 Total delta inflow from Brahmani and Baitarani basins due to net rainfall of 10 mm in one hour, with the uncontrollable and controllable runoff volumes

## Float-counter-weight water level sensor with shaft encoder

### Conditions and Requirements

- The sensor shall be of such a design that it operates reliably and accurately under the prevailing environmental and operational conditions.
- The sensor shall be easy to operate and maintain.
- All materials on the sensor exterior shall be non-corrosive.
- The associated data logger zero shall be adjustable to zero of gauge.
- The sensor will be installed in a stilling well.
- The size of float and counter weight shall allow free movement in a (stilling) well. The inner well diameter shall allow for a free space around float and counter weight of 50 mm or more.
- The sensor shall be supplied with the accessories as needed for effective deployment.
- The sensor shall have an expected technical lifetime of not less than 10 years.
- The sensor shall be capable to operate for at least 6 months without any servicing.
- Operator's and maintenance manuals, related to the type and model of the sensor, shall be part of the delivery.
- Comprehensive operators and maintenance training for respectively field observers and sensor specialists shall be part of the delivery.
- The proper functioning of each sensor shall be demonstrated at delivery.

### Specifications

The purchaser may execute his judicious discretion in the choice of configuration and options.

### 1. Sensor

| | |
|---|---|
| **sensor type** | shaft encoder with float and counter weight |
| **measuring range** | 0 to 20 m water level fluctuation |

The Schedule of Requirements gives the numbers to be quoted for. It is attached to this document. The Bidder shall specify for the closest standard range of the offered product with respect to the required measuring range. The quoted range shall be equal or larger than the required range.

| | |
|---|---|
| **suspension** | perforated tape or beaded wire |
| **pulley** | fitted with matching sprockets for perforated tape or matching cavities for beaded wire |
| **overall accuracy** | 0.005 m |

The accuracy also includes the longitudinal properties of the float suspension and the shaft encoder accuracy. The positioning of perforations/beads shall comply with the accuracy requirement.

| | |
|---|---|
| **long term stability** | 0.002 m/year |

Stability shall also cover the longitudinal tape/wire properties, e.g. elongation, contraction and creep of the suspension at the specified length.

| | |
|---|---|
| **reproducibility** | 0.001 m |
| **resolution** | 0.001 m |
| **rate of rotation** | 1 m/s |

The sensor should keep track of rapid water level movements without suffering from missing increments due to too slow operation.

| | |
|---|---|
| **enclosure material** | FRP, cast metal or similar |

The sensor enclosure and all its components that are exposed to the environment shall be of corrosion proof material. Moreover, in particular the interface from the pulley axle to the shaft encoder electronics requires specific attention; it is of great importance that the shaft encoder electronics are fully protected against ingress of water, moisture, dust, etc. The shaft rotation should not be hampered by the ingress protection.

| | |
|---|---|
| **ingress protection** | the electronics section of the sensor, its enclosure and cable passage(s) should comply with IP65 protection |
| **operating temperature** | 10 to 60°C |
| **humidity** | 100% |
| **over-voltage protection** | on all i/o lines, regardless mode of connection during deployment |

## 2. At data logger end

| | |
|---|---|
| **recording capacity** | minimum of 20,000 water level readings |
| **recording resolution** | 0.001 m |
| **water level indication** | LCD display with 0.001 m resolution (optional) |
| **over-voltage protection** | on all i/o lines, regardless mode of connection during deployment |

## Vented gauge pressure sensor

### Conditions and Requirements

- The sensor shall be of such a design that it operates reliably and accurately under the prevailing environmental and operational conditions.
- The sensor shall be easy to operate and maintain.
- All materials on the sensor exterior shall be non-corrosive.
- The data logger zero shall be adjustable to zero of gauge.
- The method of pressure measurement shall compensate for the effects of air-pressure, e.g. by application of a vented gauge pressure sensor or other compensation method.
- The sensor shall not need a stilling well for wave and turbulence suppression but shall have a wave suppression filter implemented in software.
- The sensor shall be supplied with the accessories as needed for effective deployment.
- The sensor shall have an expected technical lifetime of not less than 10 years.
- The sensor shall be capable to operate at least 6 months without any servicing.
- Calibration data and test certificate shall be part of the delivery.
- The data logger shall support adjustable specific gravity over a range of 0.9 to 1.03.
- Operator's and maintenance manuals, related to the type and model of the sensor, shall be part of the delivery.
- Comprehensive operators and maintenance training for respectively field observers and sensor specialists shall be part of the delivery.
- The proper functioning of each sensor shall be demonstrated at delivery.

### Specifications

### 1. Pressure sensor

| | |
|---|---|
| **sensor type** | vented gauge pressure sensor |
| **measuring range** | 0 to 15 m water column |

The Schedule of Requirements gives the numbers to be quoted for. It is attached to this document. The Bidder shall specify for the closest standard range of the offered product with respect to the required measuring range. The quoted range shall be equal to or larger than the required range.

| | |
|---|---|
| **overall accuracy** | 0.01 m |
| **temperature coefficient** | **<**0.001 m/ºC (on water level reading including 50 m suspension cable) |
| **long term stability** | 0.01 m/year |
| **reproducibility** | 0.005 m |

**Note:** Overall accuracy, long term stability and reproducibility include pressure sensor, cable and data logger. Stability shall also cover the longitudinal cable properties, e.g. elongation, contraction and creep of the suspension cable at the cable length specified in the Schedule of Requirements.

The temperature coefficient covers all the combined temperature effects on pressure sensor, data logger (zero and scale) and suspension cable.

The vendor shall specify the temperature effects on: sensor reading (zero and scale effects), cable length and data logger. The sensor shall maintain the specified **overall accuracy** over a temperature fluctuation of at least 10ºC, i.e. whatever the actual temperature coefficient, the overall error shall not exceed the accuracy specifications as given under the item ‘overall accuracy’.

**overload pressure** 2 times Full Scale

Overload pressure is the maximum pressure the sensor can sustain without effect on calibration upon return to the rated measuring range.

**burst pressure** >3 times Full Scale

Loading a sensor beyond the burst pressure most likely results in puncture or collapse of the sensor membrane(s). Water may invade into the electronics compartment, damage the sensor severely, and destroy recorded data.

**over-voltage protection** on supply and sensor wires

All pressure sensors suspended on a cable shall have an in-built protection against over-voltage in addition to an over-voltage scheme on the associated datalogger electronics.

**2. At data logger end**

**resolution of measurement** 12 bit A/D converter or better
**settling time** <60 minutes after submersion at the time of installation.

Upon installation, after submersion, the data logger including pressure sensor and electronics, adjusts to the changed temperature, pressure and cable tension; the water level readings shall settle to the required accuracy within the specified settling time.

**wave attenuation filter**

The wave attenuation filter, which is implemented in software is defined by two controls, viz.:

- sampling interval in seconds, e.g. 1 to 10 seconds
- averaging number, e.g. 1 to 240 samples

The data logger should at least be capable to take the average of 30 or more samples collected over a period of 30 seconds or more. Only the average value is recorded.

**recording capacity** ≥20,000 water level readings.
**recording resolution** 0.001 m or better
**operating temperature** 10 to 60°C.

The operating temperature range specification applies to all components associated with the water level measurement, like: sensor, cable, data logger, batteries, etc.

| | |
|---|---|
| **water level indicator** | LCD display with 1 mm resolution (optional) |

## 3. Enclosure for pressure sensor

The sensor enclosures shall comply with the following specifications.

| | |
|---|---|
| **material** | stainless steel (AISI 316) or equivalent |
| **mass** | sufficient to keep suspension cable taut, e.g. 2 to 4 kg |
| **ingress protection** | enclosure and cable assembly should have IP68 protection to a minimum of 50 m water column |

## 4. Cable

The design of the support for the water level sensor depends on the site-specific conditions. The engineer in charge shall provide details on support and housing in collaboration with the bidder. The cable may be of a detachable type for increased operational flexibility.

The cable shall have the following features:

- strength members for good longitudinal stability of the cable;
- incorporated vent tube for barometric air-pressure compensation of the vented gauge pressure sensor;
- a moisture blocking system based on a hydrophobic filter and desiccator, to prevent condensation of water in the vent tube and in the sensor. The desiccant capacity shall be sufficient for 6 months of unattended operation. The desiccant shall be field replaceable.
- the desiccant capacity should be adequate for at least 4 months of unattended operation under worst case environmental conditions. For each sensor, two desiccant replacements should be part of the delivery.
- good flexibility;
- cable screen, to be connected to the data logger ground terminal to minimise electrical interference.
- a cable suspension bracket allowing the data logger to be adjusted to the required depth, in a stable and reproducible manner

### Quantitative specifications

| | |
|---|---|
| **conductor size** | minimum 26 AWG 19/38 tinned copper wires with insulation like nylon or PTFE (Teflon), insulation thickness $\geq$0.5 mm |
| **vent tube** | Nylon, PTFE or equivalent, inner diameter approx. 1.5 mm, thickness minimum 0.4 mm |
| **strength members** | stainless steel, Kevlar or equivalent to keep the sensor at the correct suspension depth |
| **temperature coefficient** | <15 x $10^{-6}$ /°C (longitudinal) |
| **cable screen** | braid of 36 AWG tinned copper or similar effective material |
| **outer jacket** | Surlyn, Polyurethene, PTFE (Teflon) or similar; minimum thickness 1 mm |
| **cable size** | outer diameter 7 to 12 mm |
| **cable length** | to be specified in m<br>as per Schedule of Requirements |

## Tipping Bucket Raingauge

### Conditions and Requirements

- The rain gauge shall be of such a design that it operates reliably and accurately under the prevailing environmental and weather conditions.
- The rain gauge shall be easy to operate and maintain.
- The rain gauge shall be supplied with the accessories as needed for effective deployment.
- All materials on the rain gauge shall be non-corrosive.
- All materials on the rain gauge that are exposed to sunlight shall be UV radiation resistant.
- The rain gauge shall be sturdy and shall withstand exposure to extreme climatic conditions.
- The rain gauge shall withstand attack by fungi, insects, rodents and other small creatures.
- The rain gauge shall have a smooth and permanent surface finish to minimise evaporation losses.
- The height of the rain gauge shall be small enough to allow the collector opening to be installed at standardised heights in compliance with Indian and WMO standards.
- The minimum expected operational lifetime shall be 10 years without loss of functioning.
- All openings of the rain gauge shall be covered with stainless steel net to protect against any insects entering inside.
- Appropriate surface treated mounting bolts (M 6 x 130) with nuts and washers shall be supplied.
- The tip detector shall feature in-built lightning protection.
- The rain gauge shall have leg adjusters to set the rim horizontally.
- A spout filter shall prevent ingress of insects and debris.
- A certified calibration test document shall be part of the delivery.

### Specifications

#### 1. Tipping bucket

| | |
|---|---|
| **rim material** | gun metal / brass / aluminium alloy |
| **collecting funnel** | 200 mm internal diameter or similar |
| **bucket size** | 0.5 or 1 mm |
| **depth from rim to funnel** | ≥175 mm |
| **sensor** | reed switch |
| **accuracy** | 2% of reading for non-monsoon conditions<br>5% of reading under monsoon conditions, e.g. 100 mm in 15 minute period |
| **output** | between 10 and 100 ms switch closure |

## 2. At data logger end

| | |
|---|---|
| **tip detector input** | bounce protected |
| **switch compliance** | minimum switch close time <10 ms |
| | minimum switch open time <100 ms |
| **recording** | tip-count, accumulated over recording interval |
| **recording interval** | settable from 1 minute to 24 hours |
| **counter capacity** | ≥12 bit counter |
| **recording capacity** | ≥20,000 tip-counts |
| | |
| **operating temperature** | 10 to 60°C |
| **operating humidity** | 0 to 100% |

## Data logger

### Conditions and Requirements

- The data logger shall be of such a design that it operates reliably and accurately under the prevailing environmental conditions.
- The data logger shall be easy to operate and maintain.
- All materials on the data logger exterior shall be non-corrosive.
- All batteries associated with the data logger and the DCU (Data logger Control Unit), i.e. the batteries for normal operation and the backup batteries, shall be easily replaceable.
- During battery replacement, the data logger settings and data shall be retained.
- The data logger shall be supplied with the accessories as needed for effective deployment.
- The data logger shall have an expected technical lifetime of not less than 10 years.
- The data logger shall be capable to operate at least 6 months without any servicing.
- The sensor readings shall be recorded in data logger memory.
- The data logger shall support the data communication protocol as implemented in the data communication system to the extent that effective data exchange and data logger control as required for the telemetry application is fully supported.
    1. retrieval of last record
    2. retrieval of specific record by given date and time
    3. remote adjustment of recording interval and data logger clock
- An error monitoring and remedying communication protocol shall be used for data exchange. The protocol shall ascertain error free data exchange between data logger and DCU/PC/Data Communication System.
- The communication protocol shall be based on packet wise data exchange; the packets shall be accompanied by a CRC code for checking at the receiving end. Defective or not received packets shall be retransmitted upon request by the receiving end.
- The data logger shall be capable to measure the supply voltage and preferably also the charge/discharge current to/from the battery.
- Operator's and maintenance manuals, related to the type and model of the data logger, shall be part of the delivery.
- Comprehensive operators and maintenance training for respectively field operators and data logger specialists shall be part of the delivery.
- The proper functioning of each data logger shall be demonstrated at delivery.

### Specifications

### 1. Data logger

| | |
|---|---|
| **resolution of measurement** | 12 bit A/D converter or better |
| **measuring interval** | pre-set at 1 hour, adjustable from 10 minutes to 24 hours. |

The measuring interval shall be user adjustable, recordings shall be executed at 'integer times'. Example, if the measuring interval is 30 minutes, then recording should take place at 00h00, 00h30, 01h30, etc. The first record after initiation of the data logger, should be made at the first instant of 00 or 30 minutes in the hour.

| | |
|---|---|
| **date** | day, month, year in the following format: DD/MM/YYYY with leading zero's (01/03/2001 for 1st of March 2001)<br>No millennium bug, i.e. Y2K compliant. |
| **time** | hh:mm:ss (0 to 23 hours, 0 to 59 minutes, 0 to 59 seconds) with leading zero's (08:05:07) |

The specification given above is only valid for the way date and time are presented to the user and does not apply to the way the data loggers handles these.

**recording capacity** ≥20,000 water level and rainfall records, including time stamps.

The recorded data shall also contain a data logger serial number and/or station identification code and information on date and time of recorded water levels readings. The serial number shall be uniquely attached to the data logger. The station identification code shall be attached to the data logger at installation and shall not be added after data retrieval by user interference. The memory shall have a ring organisation (endless loop). The memory shall be protected against accidental erasure by a password or equivalent.

**error marking** error code, e.g. –9999 or similar

Out of range data and errors shall be clearly and unambiguously marked and be distinguishable from valid data. The error mark is an impossible value, which cannot be generated by valid measurements.

**memory type** non volatile memory or volatile memory

Volatile memory (RAM) shall be protected from data loss by a lithium backup battery. The battery capacity shall be sufficient to retain memory contents more than one year after main power disconnection (removal of the supply batteries).

| | |
|---|---|
| **power supply** | power shall be derived from the external battery backed power supply |
| **communication interface** | serial RS232 C |
| **baud rate** | 9600 or more |
| **operating temperature** | 10 to 60°C |
| **in-built clock** | time keeping better than 1 minute per month |
| **displayed time resolution** | 1 second |
| **over-voltage protection** | on all i/o lines, regardless mode of connection during deployment |

Built-in over-voltage protection is required on the electronics unit, in particular on all external connections, e.g. sensor supply and signal, external power supply and data communication interface.

## 2. Enclosure of data logger

The data logger, electronics, back-up batteries and all other electrical components shall be contained in one or more protective enclosures. The enclosures shall comply with the following specifications.

| | |
|---|---|
| **dimensions** | not specified |
| **material** | sturdy, stable, corrosion proof |
| **ingress protection** | enclosure, connectors and cables shall be protected in compliance with IP65 |
| **operating temperature** | 10 to 60°C |
| **humidity** | 100% |

## 3. Cables

The cables may be of a detachable type for increased operational flexibility.

The cables shall have good flexibility and be supplied with a screen, the latter to be connected to the data logger ground terminal to minimise electrical interference, o.a. due to radio transmissions.

### Quantitative specifications

| | |
|---|---|
| **conductor size** | minimum 26 AWG 19/38 tinned copper wires with insulation like nylon or PTFE (Teflon), insulation thickness ≥0.5 mm |
| **cable screen** | braid of 36 AWG tinned copper or similar effective material |
| **outer jacket** | Polyurethene or equivalent; minimum thickness 1 mm |
| **cable size** | outer diameter 7 to 12 mm |
| **cable length** | to be specified in m |

## 4. Data logger Control Unit

- The Data logger Control Unit (DCU) shall be portable, handy and lightweight (e.g. a palmtop computer).
- The delivery shall include cables for connecting the DCU to the data logger and to a serial port of a PC.
- The DCU shall communicate by a serial protocol.
- For some data logger implementations, the interface adapters, e.g. for IrDA and RS485, are needed to communicate with DCU and/or PC. These adapters, including manuals, software, cables and all other required accessories shall accompany each DCU, both for communication between data logger and DCU between data logger and PC.
- If required for use with the DCU and/or PC, e.g. to cope with long cable lengths, suitable adapters shall be part of the delivery.
- The DCU shall support the communication protocol as specified under Data logger, item Communications.
- The data exchange between data logger and DCU as well as between DCU and PC shall be protected by similar error-free protocols.

The DCU shall have the following features:

| | |
|---|---|
| **data handling** | capable of programming, controlling and monitoring the data logger |
| **capacity** | sufficient to offload all data of 10 entirely filled data loggers |
| **ports** | at least one serial RS232 port to connect a data logger or a PC |
| **baud rate** | 9600 or more, matching the data logger |
| **entry and display** | keyboard and LCD screen for efficient control of the data logger |
| **software functions** | data logger control functions, display of historical data, battery voltage, present water level reading and data logger time |
| **entry and display** | keyboard and LCD screen for efficient control of the data logger |
| **readability** | the display shall be easily readable under field conditions |
| **software functions** | data logger control functions, display of historical data, battery voltage, present sensor reading and data logger date/time |
| **operating system** | capable of running MS-Windows CE (preferably), MS-Windows95/98 operating system with matching software for data logger control and tabular and graphical presentation of time series of collected data on the LCD screen. |
| **power supply** | operative with standard Alkaline batteries, easily available in India, or with a rechargeable battery pack |
| **power autonomy** | at least 12 hours continuous operation on a single battery charge |
| **supply backup** | all volatile data have to be protected by a back-up battery of sufficient capacity to retain all data for at least one year of failure of main batteries |
| **mass** | less than 0.5 kg |
| **operating temperature** | 10 to 60°C |
| **humidity** | 95% |
| **robustness** | the DCU should be capable to survive a few drops on stone. |