# Government of India

## National Project Monitoring Unit (NPMU)

## National Hydrology Project (NHP)

**Loan No 8725-IN**

## Ministry of Water Resources, River Development & Ganga Rejuvenation,

***INTERNATIONAL COMPETITIVE BIDDING***

# Request for Expression of Interest (REOI) for Consultancy Services for "WATER ACCOUNTING AND INTEGRATED RESERVOIR OPERATIONS FOR NARMADA RIVER BASIN" for National Hydrology Project

## March, 2019

**2nd Floor, Rear Wing, MDSS Building,**
**9, CGO Complex, New Delhi-110003.**
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**CONSULTANCY FOR 'WATER ACCOUNTING AND INTEGRATED RESERVOIR OPERATIONS FOR NARMADA RIVER BASIN'UNDER NATIONAL HYDROLOGY PROJECT**

No.NHP-05/2019 Date:01-03-2019

**Request for Expressions of Interest(REOI)**

1. This Invitation for Bid follows the General Procurement Notice for this Project that appeared in Development Business on 21/09/2016.
2. The Government of India has received a loan from the World Bank under the National Hydrology Project(NHP) and intends to apply part of the loan proceeds to make payments under the contract for 'Water Accounting and Integrated Reservoir Operations for Narmada Basin'.
3. NHP is countrywide project, with 49 Implementing agencies (IAs) including eight central agencies, 39 state-UT level agencies and two river basin organizations (RBO). The National Hydrology Project (NHP) is proposed to be an eight-year project starting from November, 2016. It aims for Integrated Water Resources Management to enable improved decisions in water resources planning and operations. This requires not just improved water information systems and Decision Support Systems, but also enhanced institutional capacity – both technical capacity and policy & planning capacity. The Project Development Objective of the project is proposed "**to improve the extent, quality, and accessibility of water resources information and to strengthen the capacity of targeted water resources management institutions in India**".

   Narmada River Basin is spread over five states in India. There had been dispute over the use of Narmada Water. Narmada Water Dispute tribunal (NWDT) has apportioned Narmada water and Hydro power amongst the party states. NWDT also stipulated setting up of Narmada Control Authority which started functioning since 20$^{th}$ December, 1980. Narmada Control Authority (NCA) which is comprises of representatives from states of Madhya Pradesh, Gujarat, Maharashtra and Rajasthan. The current water accounting procedures implemented by NCA are conducted using spreadsheets. NCA is intending to replace the spreadsheet- based water accounting with a modern computer modeling tool that will assist with river basin planning and management, including water accounting as one of the functionalities available to the NCA staff. The principal goals of this project are to acquire modern water management software and apply it in the Narmada river basin, both as a river basin planning tool that will allow investigation of the impacts of various decision making scenarios related to future water use, as well a seasonal operational tool to assist with the current reservoir operation and management of water use.

**Objectives of consultancy:**

The consultant should study the requirements for river basin modeling outlined in the technical section of this document and provide both the description of the proposed modeling tool as well as the solution to the test problem that will form part of the evaluation matrix. Consultants that provide high quality solutions to the test problem and meet other requirements of this EOI may be shortlisted and invited to submit their technical and financial proposal in the second phase. The ultimate goal of this consultancy is to provide a modern river basin modeling tool which meets the highest standards in the industry, along with training workshops, technical support and troubleshooting. This will also include development of a customized dashboard for the Narmada reservoir operation system that allows simple and easy selection of input data, entry of input and provide options for selection and generation/ display of output data tailor-made to suit the needs of administrators/ technocrats/ intermediate level officers/ experts. These services will be provided to the NCA staff in their transition from the current spreadsheet-based water accounting to the modern river basin modeling using the best available tools and technologies.

**DURATION:**

Total anticipated project duration is 24 months. Of those, the last 12 months are devoted to Technical Support after Implementation. NCA reserves the right to evaluate if additional Technical Support Services contract will be required after the initial 24 months period.

## 4. SCOPE:

The broad scope of the study will consist but not limited to the brief given below. The detailed scope of the study is provided in Terms of Reference (ToR) as **Attachment 1**. Detailed TOR shall be issued along with the final Request for Proposal.

***Development and verification of historic natural flows at critical locations in the basin for all years where sufficient historic records are available.*** NCA has developed estimates of virgin (natural) flows at several locations in the river basin using a 10-daily time step for 28 years of data. Those estimates should be verified, corrected if necessary, and extended to include as many historic years as possible. Critical locations in the basin represent locations of major reservoirs and diversion structures, which may or may not coincide with the locations of hydrometric stations. Consultants are expected to use the project depletion method that reconstructs historic natural flows on the basis of recorded storage levels, estimated net evaporation on the reservoir, and recorded reservoir outflows. For years before the reservoirs were built, natural flows can be assessed using recorded flows at hydrometric stations adjusted by the estimates of upstream water use. Natural flows should be developed for 10-daily time steps that will eventually be used as input series for the selected river basin model. The consultant will review all available data sources and propose methodology to extend the estimates of historic natural flows for as many years as possible assuming the common period for all critical locations. Estimates of precipitation that occurred directly on the reservoirs as well as evaporation should also be collected by the Consultant from IMD/CWc/NCA or any other reliable source.

***Setting up of the selected River Basin Model for use as a planning tool and as an operational tool.*** The use of river basin model as a planning tool is predicated on the use of historic natural flows. Consultants should set up the model such that it can easily allow evaluation of various operational scenarios. The model should include all relevant storage and diversion structures in the Narmada River Basin, the list of which will be provided by the NCA staff. The customized dashboard should be developed in a way that allows regular operation of inputs and outputs in a simplified manner, with minimal training requirement.

The use of the model as an operational tool will request that consultants modify the model such that it can eventually tie into the results of the Early Hydrologic Prediction (EHP) project that will provide hydrologic forecasts for up to three months in low flow seasons.

***Training of NCA staff.*** There will be 8 training sessions, each lasting 2 days in specified locations within Narmada Basin, generally at NCA headquarters Indore and party state capitals.

***Technical Support and Troubleshooting.*** Some technical support and assistance will be required in the first 1 year of the model use by the NCA staff.

**IMPLEMENTATION ARRANGEMENT**

The Project Implementation plan of the Consultancy is broadly divided into the following phases:

**Phase I:** Evaluation of the available historic hydro-meteorological data and development of historic natural flows for all relevant locations in the basin and for all years for which sufficient data records exist. This phase also includes collection of all climate data from IMD or other relevant sources.

**Phase II:** Model setup as a planning and operational tool. Development of selected modeling scenarios for planning and real time operation and production of technical documents. Development of the customized dashboard for the Narmada basin reservoir operation system.

**Phase III:** Training seminars and workshops, technical assistance and trouble shooting. Includes upgrade to software necessitated due to updates in hardware/ software/ network/ data availability/ new scenarios cropping up at a later stage.

5. **National Project Monitoring Unit, National Hydrology Project, Ministry of Water Resources, RD & GR** now invites eligible consultants to indicate their interest in providing the above required consultancy. Interested consultants must provide information indicating that they are qualified to perform the services (brochures, description of similar assignments, experience in similar conditions, availability of appropriate skills among staff, etc.) as per Performa attached from **Annexure-I to VIII.**

6. **Consultants may associate with other firms/ consultants to meet the necessary qualification criteria or enhance their capability. The EOI submitted by consultants in association should clearly indicate the nature of the association if it is a joint venture or a sub-consultancy. In case of Joint venture, the name of the lead firm should be clearly stated and the JV should not have more than three members including the lead.**

7. The criteria for short listing of the Consulting firms shall be as follows:

a) The firm /institute must have been in business in water resource sector for at least the last ten years (Copy of the Certificate of Incorporation or Memorandum of Articles).

b) Organization set-up, structure and availability of key professionals (Senior Hydrologist/River Basin Modeler, Hydrologist/River Basin Modeler, IT Programmer/ Database specialist etc.) of required qualification with the firm i.e. Technical team and expertise available with the organization (attach short CVs for reference only).

c) The firm / institute must have successful experience of executing at least one similar project/s in last ten calendar years including 2018 (Enclose list of relevant assignments executed with customer name & address, contact details, order value and performance certificates) in the basin(s) /sub-basin(s) for an area of at least 20,000 Sq. Km encompassing the key components of water accounting and integrated reservoir operations namely input data development and its validation, model development, analyses of model results for various scenarios, development of user-friendly model interface/dashboard for linking the model to other data bases. The Firm / research institute must have experience of working with governments/ state owned enterprises.

d) The firm(s) / institutes, including the JV partners and sub-consultants, should have at least 40% of the key professionals, including Team Leader as permanent employees.

e) The firm should have sound financial performance and resources i.e. the firm should have average Annual turnover (last five financial years) of more than USD 3.0 million. In case of JV, the lead member shall have minimum USD 1.8 million of average annual turnover and other members shall be minimum USD 1.00 million.

f) In case of Research Institute meeting the eligibility requirements intending to apply solely or as JV for these studies, the average annual turnover clause at (e) above would not be applicable. However, in case of JV with any private entities, the annual average turnover clause (e) above will be applicable to JV only either as lead partner or otherwise.

g) Along with above criteria, the selection process will involve a test run of model with data for 9 years developed for the Narmada Basin (**the input data is attached along with ToR and soft copy of data in excel format can be downloaded from National Hydrology Project Web Site URL:** http://www.nhp.mowr.gov.in/docs/narmadadata.xlsx). They prospective consultant team would run their models of choice, provide solutions to the client. The data required for test run of the model can be downloaded in excel format from NHP website www.nhp.mowr.gov.in. Government of India will own the modeling results presented by every vendor and it reserves the right to use these results in future model selections on similar studies. The team with results closest to the model results obtained and reserved by the advisory team of the client would be selected for participation in the financial bid and further negotiations.

8. **Prior to submission of EOI by the bidders, a conference shall be held on 18-03-2019 at 1100 hrs. at 2nd Floor, Rear Wing, MDSS Building, 9, CGO Complex, New Delhi-110003.to clarify the queries of the bidders regarding the problem statement.**
9. The attention of interested Consultants is drawn to paragraph 1.9 of the World Bank's Guidelines: Selection and Employment of Consultants under IBRD Loans and IDA Credits & Grants by World Bank Borrowers dated January 2011 ("Consultant Guidelines"), revised Jul 2014, setting forth the World Bank's policy on conflict of interest.
10. A Consultant will be selected in accordance with the CQS (Selection based on Consultants' Qualifications) method set out in the World Bank "Guidelines: Selection and Employment of Consultants under IBRD Loans and IDA Credits & Grants by the World Bank Borrowers- Jan 2011, modified July 2014.
11. Interested Consultants may contact at Tel: +91-11-24363417; E-mail: sjc2nhp-mowr@gov.in for any further information.
12. The Request for Expression of Interest will be available on the NHP's website at URLhttp://nhp.mowr.gov.in. The prospective bidders are required to register on e-procurement website i.e. https://eprocure.gov.in/eprocure/app at no cost and prior to the submission of proposals. The bidders are also required to have a Digital Signature (DSC) from

one of the Government of India authorized Certifying Authorities in order to submit a proposal on line at the web address indicated above (https://eprocure.gov.in/eprocure/app), The list of the authorized Certifying Authorities can be found onhttp://www.cca.gov.in/cca/

13. Expression of Interest with all relevant information and documents can be downloaded on https://eprocure.gov.in/eprocure/app for "CONSULTANCY FOR 'WATER ACCOUNTING AND INTEGRATED RESERVOIR OPERATIONS FOR NARMADA RIVER BASIN' UNDER NATIONAL HYDROLOGY PROJECT" **from 05-03-2019 to 16-04-2019 15:00 hrs Server time.** The Expression of Interests received till the appointed time and date shall be opened same day at 15.30 hrs. Server time. In the event, this last date being declared as holiday by the Government, above EOI will be opened on the next working day at the same time.
14. The electronic bidding system will not allow any late submission of the REOIs after due date and time as per server time. Physical, Email, Telex, cable or facsimile submission of REOIs will be rejected as non-responsive. Intending Bidders are advised to visit NIC e-procurement web site URL https://eprocure.gov.in/eprocure/app. and NHP website http://nhp.mowr.gov.in prior to closing date of submission of REOI for any corrigendum / amendment.

Senior Joint Commissioner-II,
National Project Monitoring Unit
National Hydrology Project,
Ministry of Water Resources, River Development, RD & GR
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9, CGO Complex, New Delhi-110003.
Tel: +91-11-24363417
E-mail: **sjc2nhp-mowr@gov.in**

**Annexure-I**

**Expression of Interest Form for Consulting Engineering Firm or Joint Venture (To be filled up by each of the constituent in case of a Joint Venture)**

*1.*

| **Consultant** | **Date of Establishment** | **Country** | **Type of organization** | | | |
|---|---|---|---|---|---|---|
| | | | *Individual* | *Partnership* | *Corporation* | *Other* |
| *Name* | | | | | | |

2. *Corporate/registered Office / Business Address / Telephone Nos. / Cable Address/ E-mail address of consultant and its branch offices for Consultant (including members in case of JV)*
3. *Consultant's former name and year of establishment (including that of members in case of JV)*
4. *Narrative description of Consultant firms if any (Use other sheet, if necessary)*
5. *Name of, not more than two (2) principals who may be contacted with title, telephone number/ fax number, E-mail address.*

**Financial Statement of the three financial Years**

| *Sr. No.* | *Particulars* | | *2017-2018* | *2016-2017* | *2015-2016* | *2014-2015* | *2013-2014* |
|---|---|---|---|---|---|---|---|
| *1.* | *Annual turnover from Consulting business* | *Lead member* | | | | | |
| | | *other member(1)* | | | | | |
| | | *other member(2)* | | | | | |
| *2* | *Net Profit.* | *Lead member* | | | | | |
| | | *other member(1)* | | | | | |
| | | *other member(2)* | | | | | |

***Notes:***

i. Values should be duly certified by statutory body like Chartered Accountant or Independent Auditors who are competent to do so as recognized by the Government of India.

ii. The amount shall be stated in Indian Rupees (INR).

iii. For the purpose of short listing, conversion to Indian Rupees shall be based average of the buying and selling rates of Reserve Bank of India as on the Proposal submission date.

iv. In case the exchange rate for any currency is not available as per the provision of this section, then Ministry of Water Resources, RD & GR reserves the right to use the rate available from an alternative source at its sole discretion.

*Annexure-III*

## Organizational Strength

### 1. Staff strength of the Organization/s

| S No. | Area of Expertise | Total No. of Staff | No. with Doctoral Degree | No. with Post-graduate Degree | No. with Graduate Degree | No. of Permanent Employees | No. of years with the firm |
|---|---|---|---|---|---|---|---|
| i. | Senior Hydrologist/River Basin Modeler | | | | | | |
| ii. | Hydrologist/River Basin Modeler | | | | | | |
| vi. | IT Programmer / Database Specialist | | | | | | |

### *2. Keys Experts/ Project Staff that would form the team in RFP*

| Project Position | Minimum Qualifications and Experience |
|---|---|
| Senior Hydrologist /River Basin Modeler | Master degree in Water Resources/ hydrology/Hydraulic Engineering or related field.<br>At least 15 years working experience in water resources.<br>Preferably knowledge about hydrological and river basin modeling tools.<br>Having sound knowledge and experience of handling optimal water allocation using multi-reservoir simulation.<br>Should have handled at least two projects as a Team Leader/Deputy Team leader in international project in water resources.<br>Should have been with bidding firm for the past 2 years |
| Hydrologist/River Basin Modeler | Master degree in Water Resources/ hydrology/Hydraulic Engineering or related field.<br>At least 10 years working experience in water resources.<br>Preferably knowledge about hydrological and river basin modeling tools.<br>Having sound knowledge and experience of handling optimal water allocation using multi-reservoir simulation.<br>Extensive knowledge of hydrological and meteorological modeling tools with good experience of rainfall- run-off modeling<br>Proven experience in inferential statistics |
| IT Programmer / Database Specialist | Graduate in Engineering in Computer Science/IT/Engineering/MCA<br>Minimum 7 years of experience in the development and maintenance of software application in science and engineering, web design and management<br>Extensive experience in scripting using Java or other similar related tools<br>Experience in statistical inferential model development and application would be an asset |

*Annexure-IV*

**Office Logistics and Software Availability**

a) Office space in sq. m. and ownership status

b) List of Hydro-Metrological along with Modelling Software available

| Name of Software | Whether Web Enabled? | Number of Concurrent Users | Cost of Purchase In Rs. | Year of Purchase | Utility and Functions of the Software |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |

*Annexure-V*

**Details of Experience**

| Sr. No | Projects Name / Year | Type of services rendered including' (A, B, C, D) | Cost of the assignment of category 'A' Rs. in Cr. | Cost of the assignment of category 'B' Rs. in Cr. | Cost of the assignment of category 'C' Rs. in Cr. | Cost of the assignment of category 'D' Rs. in Cr. | Client (With complete address, contact person, telephone No. Fax No and E mail address) | Fee in INR (Applicant's share in case of JV/ Consortium) | Completion certificate from client (Reference page no) | Duration in months | Fundin g Agency | Sole / JV/ Consortium (if JV-state Lead /Partner with share) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1 | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |

A. Hydrological analysis and modelling, validation and filtering of hydro-meteorological data sets
B. River basin modelling, analysis of various scenarios for water accounting and integrated reservoir operations
C. Dashboards for hydro-meteorological applications, water accounting and river basin modelling
D. Capacity building and trainings in the field of hydro-metrological analysis, water accounting and river basin modelling etc.

***Note:*** Only those assignments shall be considered for which consultant has provided services as lead member in case that work is done by a JV/ Consortium. Each assignment shall be supported by following details:

Name of Overall assignment: ..........................................................................................................

Location of Overall assignment: ......................................................................................................

Owner's Name and Address: ...........................................................................................................

Completion (Actual/Estimated vis-à-vis Stipulated): ......................................................................

Description of assignment: ..............................................................................................................

Description of Services provided by the firm: ................................................................................

Authorized Signatory

Name of the client:

***Annexure-VI***

## Employer's References

***Annexure-VII***

**Evaluation Criteria for Test Model Results**

***Please refer to the Section 3.2, Table 2 of Document on "Narmada RBM Evaluation Test" (Attachment 2)***

Assuming solutions meet the feasibility criteria, the main criteria for ranking the success of the models is the total value of the objective function for each simulated years, as explained in Section 3.2 and listed in Table 2 whose entries are defined in the Narmada RBM Evaluation Test document, along with a summary of the type and number of failures associated with problem constraints.

| Year | Objective Function Values | | | Total |
|---|---|---|---|---|
| | Flooding | Environmental Flows | Irrigation Supply | |
| 2008 | | | | |
| 2009 | | | | |
| 2010 | | | | |
| 2011 | | | | |
| 2012 | | | | |
| 2013 | | | | |
| 2014 | | | | |
| 2015 | | | | |
| 2016 | | | | |

| Year | Time Interval | Feasibility Check Table | | | | | Total Number of failures |
|---|---|---|---|---|---|---|---|
| | | Compliance with storage limits | Compliance with reservoir outflow limits | Accuracy of Reservoir Evaporation (% error compared to manual calculation) | Compliance with deficit sharing constraints | Compliance with mass balance constraints | |
| 2008 | 1 | | | | | | |
| 2008 | 2 | | | | | | |
| 2008 | 3 | | | | | | |
| . | . | | | | | | |
| . | . | | | | | | |
| 2009 | 1 | | | | | | |
| 2009 | 2 | | | | | | |
| . | . | | | | | | |
| . | . | | | | | | |

Failure to meet the expected feasibility constraints involves checks on the stated flow limits and mass balance equations that may be encountered at any node or in any simulated time interval. The formulas for calculating compliance limits in the feasibility check table are typically calculated as a relative deviation from limits given in the problem description. In particular:

- Simulated values are compared to the target values in the case of reservoir target levels (full supply, dead storage or maximum level during floods). An exceedance of more than 0.01 m above the prescribed operational limits will be considered a failure.
- Bargi Reservoir outflow limits for diversion channel 101 are compared to the maximum possible outflow limits as a function of average Bargi reservoir levels over a simulated time interval. The outflow limit function is given in Figure 2 of the Narmada RBM Evaluation Test document. An exceedance of outflows of more than 5 % above the limits defined by this curve will be considered a failure.
- Due to the different ways net evaporation is calculated within various models, the limit of +/- 2% from the results of manual calculation will be considered acceptable. The manual calculation will be based on the use of the average area over a simulated time step multiplied by the net evaporation in mm used as input data in each simulated time step.
- Deficit sharing constraints are to be spread evenly within a year for each irrigation component, and also among the components that are aimed to share deficits. This implies that relative deficits are equal for all simulated time steps within a year. There are three pairs of irrigation blocks that share the same deficits: 105 / 110, 205 /210, and 310 / 410.
- Mass balance constraint should be verified on every node of the modeling schematic in Figure 1 of the Narmada RBM Evaluation Test document. Clients will use the output in the units of volume provided by the consultants to verify this claim (consultants are asked to provide model output both in the units of volume and in the units of flow). Reservoir net evaporation calculated by the model should be provided in both units. Any imbalance between all inflows and all outflows for a node that is greater than 0.01 m3/s will be considered a violation of constraints.

Vendors should focus on Scenario 2 and Scenario 4, which will be used to evaluate model comparisons, and ensure that all constraints are met. Both tables used for verification of constraints and for calculation of the objective functions will be used in model evaluation. The models are expected to minimize the cost of having all deficits, while simultaneously complying with the model constraints defined in the Narmada RBM Evaluation Test document.

***Annexure-VIII***

**Undertaking**

I certify that the information in the above Expression of Interest forms is true to the best of my knowledge. I also understand that any misleading or wrong information will disqualified this application straightaway.

*President/*Managing Director

or

*Authorized Signatory of Applicant*

***Attachment 1***

सत्यमेव जयते

# Government of India

## National Project Monitoring Unit (NPMU)

## National Hydrology Project (NHP)

## Ministry of Water Resources, River Development & Ganga Rejuvenation,

***NATIONAL COMPETITIVE BIDDING***

## Terms of Reference (ToR) for Consultancy Services for "WATER ACCOUNTING AND INTEGRATED RESERVOIR OPERATIONS FOR NARMADA RIVER BASIN" for National Hydrology Project

## March, 2019

**2nd Floor, Rear Wing, MDSS Building,**
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**E-mail: sjc2nhp-mowr@gov.in**

Contents

**1. Background:**

Narmada is the fifth largest river in India and largest west flowing river of Indian peninsula. It originates from Maikala ranges at Amarkantak (in Madhya Pradesh) at an elevation of 900 m and flows westwards over a length of 1,312 Km before draining into the Gulf of Cambay, 50 Km west of the city of Bharuch, in the state of Gujarat. The basin lies between longitudes 72°32' and 81°45' East, and latitudes 21°20' and 23°45' North. The basin is bound by the Vindhya Range in the North, the Satpura range in the South, the Maikala range in the East and the Arabian Sea in the West. In the first 1,077 Km reach the river flows in Madhya Pradesh; the next 35 Km stretch of the river forms the boundary between the States of Madhya Pradesh and Maharashtra; and for the next 39 Km it forms the boundary between the states of Maharashtra and Gujarat; the last stretch of 161 Km lying in Gujarat. The Narmada Basin has been shown in Figure 1.

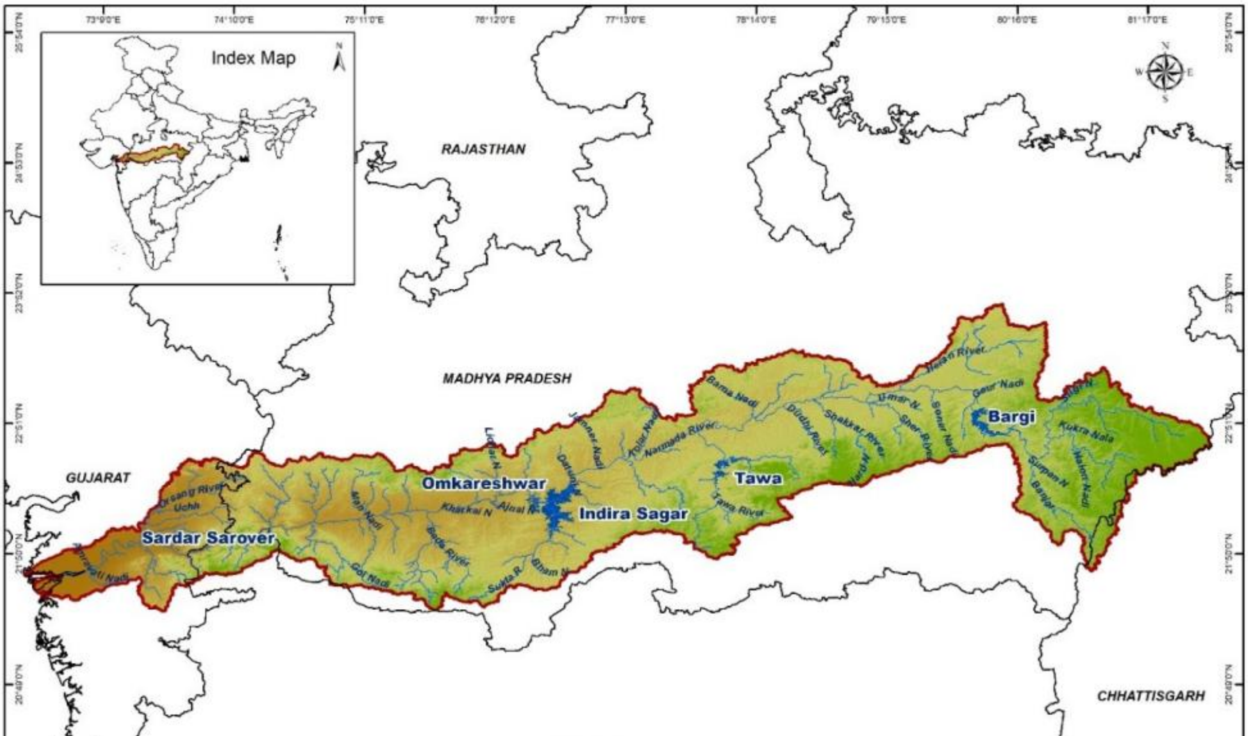



**Figure 1: The Narmada River Basin**

The development of the Narmada water resources was limited in the beginning, primarily due to the inter-State differences on sharing of water. The Central Government, by

Notification of the then Ministry of Irrigation & Power No.S.O.4054 dated 6th October, 1969, issued under section-4 of the Inter-State Water Disputes Act, 1956 (33 of 1956), constituted the Narmada Water Disputes Tribunal (NWDT) to adjudicate upon the water dispute, whereupon the decisions of the Tribunal became final and binding on the parties to the dispute. Accordingly, the NCA (Narmada Control Authority) was established, that started functioning from the 20th December, 1980. Till date the NCA has been allocating water and power to the states of Madhya Pradesh, Gujarat, Maharashtra and Rajasthan. It is based on a transparent system of sharing information on water availability and water demand, where allocation is made based on the agreement reached through consensus and trust of all the concerned parties. Even with a record of satisfactory performance in inter-state water distribution using simple calculations on Microsoft Excel, the NCA is planning to take a leap further – refining reservoir rule curves to allow optimal allocation based on a host of scenarios that can be anticipated for the future. The principal goals of this project are to acquire modern water management software and apply it in the Narmada river basin, both as a river basin planning tool that will allow investigation of the impacts of various decision making scenarios related to future water use, as well a seasonal operational tool to assist with the current reservoir operation and management of water use. The anticipated end result is better reservoir operation in terms of reduced deficits, increased reliability of supply and greater protection against floods.

## 2. Objectives of the consultancy:

The consultant should study the requirements for river basin modeling outlined in the technical section of this document and provide both the description of the proposed modeling tool as well as the solution to the test problem that will form part of the evaluation matrix. Consultants who provide high quality solutions to the test problem and meet other requirements outlined in the EOI may be shortlisted and invited to submit their bid in the second phase. The ultimate goal of this consultancy is to provide a modern river basin modeling tool which meets the highest standards in the industry, along with training workshops, technical support and troubleshooting. These services will be provided to the officers of the NCA in their transition from the current spreadsheet-based water accounting to the modern river basin modeling using the best available tools and technologies. It also includes training of officers from NCA and other associated organizations, enabling them to independently handle the software for solving problems of the future.

The broad objectives of the consultancy are:

(a) To set up water accounting model for the Narmada Basin using the modern river basin modelling approach and the best available tools and technologies for eventual use as both a planning and a low flow season operational tool.

(b) To use the selected tools to find the optimal operating rules for the five major reservoirs identified in the basin (viz., Bargi, Tawa, Indira Sagar, Omkareshwar and Sardar Sarovar Project) subject to the available inflow and demand forecasts.

(c) To develop real-time application reservoir operation tools that would be use the results of the Early Hydrologic Prediction (EHP) project to obtain inflow forecasts. The EHP project will be carried out in the Narmada River basin as part of a separate tender.

(d) To train a selected group of officers from the NCA and other associated organizations for carrying out independent operations in future after the end of the maintenance period

## 3. Scope of the Consultancy:

The Scope of the Consultancy is broadly divided in three phases as follows:

**Phase-I: Development and verification of historic natural flows at critical location in the basin for all years where sufficient historic records are available**

i. This involves evaluation of the available historic hydro-meteorological data, and development of historic natural flows for all relevant locations in the basin and for all years for which sufficient data records exist

ii. This phase also includes collection of all climate data from IMD or other relevant sources

iii. NCA has developed estimates of virgin (natural) flows at several locations in the river basin using a 10-daily time step for 28 years of data. These estimates should be verified, corrected if necessary, and extended to include as many historic years as possible. Critical locations in the basin represent locations of major reservoirs and diversion structures, which may or may not coincide with the locations of hydrometric stations.

iv. There is a possibility that daily data of longer duration may be obtained from site offices, which is currently available as hard copy format/ images etc., requiring efforts to make it amenable for input into computer program**.**

v. Consultants are expected to use the project depletion method that reconstructs historic natural flows on the basis of recorded storage levels, estimated net evaporation on the reservoir, and recorded reservoir outflows. For years before the reservoirs were built, natural flows can be assessed using recorded flows at hydrometric stations adjusted by the estimates of upstream water use.

vi. Natural flows should be developed for 10-daily time steps that will eventually be used as input series for the selected river basin model. NCA has readily available 38 years of data, however, a more comprehensive hydrologic evaluation of all available data may result in the development of longer historic series of natural flows that can be used as input data for river basin modeling. The consultant will review all available data sources and propose methodology to extend the estimates of historic natural flows for as many years as possible assuming the common period for all critical locations.

vii. Estimates of precipitation that occurred directly on the reservoirs as well as evaporation should also be collected by the Consultant. **Time: T + 5 months**

**Phase-II: Setting up of the selected River Basin Model for use as a planning tool and as an operational tool.**

This involves the setup of model as a planning and operational tool, and development of selected modelling scenarios for planning and real time operation and production of technical documents. The use of river basin model as a planning tool is predicated on the use of historic natural flows. Consultants should set up the model such that it can easily allow evaluation of various operational scenarios. The model should include all relevant storage and diversion structures in the Narmada River Basin, the list of which will be provided by the NCA staff. The use of the model as an operational tool will require that consultants modify the model in such a way that it can eventually tie into the results of the Early Hydrologic Prediction (EHP) project that will provide hydrologic forecasts for up to three months in the low flow seasons. This phase will also include conducting training for the selected officers. **Time: T + 12 months**

**Phase-III: Maintaining and updating the model.**

i. This includes organising and conducting trainings, seminars and workshops, providing technical assistance and carrying out trouble shooting

ii. This may also include incorporation of more input data, more information about future water resource plans, more scenarios; modifications required to meet advancement in hardware, software and network, etc. during the warranty period. **Time: T + 24 months**

**Note:**

1. The activities of training and capacity building are to be conducted throughout the second and third phases.

2. T is the time in month from signing of the contract

## 3.1 The key tasks in Phase-I

- Development and verification of historic natural flows at critical locations in the basin for all years where sufficient historic records are available

- Evaluation of the available historic hydro-meteorological data and development of historic natural flows for all relevant locations in the basin and for all years for which sufficient data records exist.

- Includes collection of all climate data from IMD or other relevant sources.

- May also include conversion of some additional hardcopy data into digital format suitable for analysis.

  Note: In case the required data is to be procured from any agency, prior permission of the same shall be obtained by the consultant from the client. The actual cost of the procurement shall be reimbursed to the consultant by the client.

### 3.2 The key tasks in Phase-II

- Setting up of the selected River Basin Model for use as a planning tool and as an operational tool
- Development of selected modelling scenarios for planning and real time operation and production of technical documents
- Organising and conducting training sessions to make the nominated officers of the NCA/other organisations capable to carry out river basin modelling using the selected software.

### 3.3 The key tasks in Phase-III

- Maintaining and updating the model
- Organising and conducting training, seminars and workshops, technical assistance and trouble shooting
- Incorporating more input data, more information about future water resource plans, a few more scenarios, as may be perceived
- Extra work mandated by updates in hardware, software, network etc. may also have to be performed
- The team of the officers comprising members from NCA and other associated organisations have to be trained in a way that enables them to carry out independent operations after the expiry of the maintenance period.

## 4. The Selection Process:

Along with other criteria, the selection process will involve a test run of model with data for 9 years developed for the Narmada Basin (please refer to **Attachment 2 and Input data file. The soft copy of input data in excel format can be downloaded from National Hydrology Project Web Site URL:** http://www.nhp.mowr.gov.in/docs/narmadadata.xlsx). They prospective consultant team would run their models of choice and submit their results to the client. The results of this exercise will belong to Government of India and they will be treated as public domain information of interest to future selection of river basin modelling tools on various upcoming projects. Two-separate evaluations will be conducted, one for the company profile and its consultants' team, and the other one for the proposed modelling tool. The Government of India reserves the right to negotiate with the winning consultant the final technical support contract which may not necessarily involve the modelling tool that has been proposed by the winning consultant.

## 5. Deliverables:

The deliverables will include but will not be limited to:

- Integrated river basin model for the Narmada Basin that is based on GUI and allows quick and easy operations to generate comprehendible outputs for making the decision process simpler and more logical. It should allow effortless upgrades of inputs and constraints/ scenarios.
- Inception report
- Data collection and compilation report
- Draft final report of modelling
- Final report of modelling
- Training report
- Software manuals – Quick Start Guide, User Manual, Technical Manual, Reference Manual, Troubleshooting Manual

## 6. Responsibility of the Consultant:

The responsibility of the consultant will include the following tasks:

- Conduct and complete the consultancy as per the agreed TOR and scope of the consultancy subject to the full satisfaction of the Technical Advisory and Review Committee (TARC) within the stipulated time period.
- Collect data and information required for modelling from concerned agencies. The consultants may have to acquire real time data which is not available from different state agencies and/or others if so required. The costs will be reimbursable following the prior approval by the client.
- Conduct field visits as required for data collection or to verify model results
- Work in NCA premises during project period
- Ensure presence of key staff within NCA premises during the stipulated period.
- Train a selected group of officers from NCA and other concerned agencies, enabling them to carry out independent operations on the software after the expiry of the maintenance period
- Hand over all software, hardware, data, and source code of all applications that were in public domain or that were developed as part of this project after the completion of the consultancy to the client.

## 7. Schedule for completion of tasks:

The time schedule for the proposed deliverables are given below:

| Deliverables | Description | Timing |
|---|---|---|
| 1. Inception Report | Review of data availability and data quality, Methodology for the calibration and validation of model, and fortnightly schedule of implementation work plan. | T + 1 month |
| 2. Data collection and compilation Report | Collection, Validation & Compilation of all the data Required for carrying out the modelling work (hydro-meteorological, water availability and demand, binding criteria for optimisation and preferable conditions, scenarios, any other relevant data/ information). | T + 6 months |
| 3. Draft Final report of modelling | The draft final reports shall cover complete details such as data analysis, modelling, analysis, outcome and results, recommendations, software user manual etc. | T+11 months |
| 4. Final Report | Covering all Task described in the ToR and addressing all the observations of the client on draft final reports | T + 12 months |
| 5. Capacity building and Training Report | Bringing out the different aspects of capacity building: challenges faced, lessons learnt and ways to improve for the future | T+24 month |
| * T is the time in month from signing of the contract | | |

## 8. Handling Restricted Data

The Consultants, shall not, either during the term or even after the expiration of this contract, disclose any proprietary or confidential information related to the Project, the services, this contact, or the Client's business or operations without the prior written consent of the Client.

## 9. Data Services & Facilities to be Provided by the client:

The following amenities will be provided by the Client:

- Office space and secretarial assistance at NCA headquarters in Indore
- Designated Engineers of Narmada Control Authority and the party State Governments of Gujarat, Madhya Pradesh, Maharashtra and Rajasthan

- The data collection shall be facilitated by the client by way of recommendation letters, as required. In case it is required by the consultant to purchase data, the actual cost of data shall be reimbursed to the consultant. It should be decided jointly by the client and the consultant with prior approval from the client before the procurement is made.
- The client will help to select and depute a team of young, dynamic and enthusiastic officers from NCA and other associated organisations who would work and learn under the guidance of the consultant. These officers are required to develop the requisite expertise in a step-by-step manner, so that they are able to carry out operations of the decision support system to meet new requirements/ to face new constraints independently after the end of the maintenance period.

**10. Administration**

For the purposes of this assignment, the Consultant will report to the Executive Member, Narmada Control Authority. The Consultant will work closely with the NCA offices as a Client throughout this assignment – especially to discuss interim results and on methodology. The study shall be subject to periodic guidance and review of works/ reports by a Technical Advisory and Review Committee (TARC) comprising of officers from concerned organizations and Technical and Management Consultancy unit of the National Project Management Unit of National Hydrology Project formed for this purpose.

**11. Desirable Experience of Consulting Firm and their Key Team Members:**

The lead organization for the project shall meet the following criteria

- Minimum ten years of experience in providing international consultancy services in the water sector, with particular emphasis and a track record of successfully delivering major analytical projects that directly interface with water resources policy or management.
- Demonstrated experience in carrying out river basin modelling work on at least three similar studies, and experience of working with governments/ state owned enterprises.
- The firm(s) / research institutes bidding on this project, including the JV partners and sub-consultants, should have at least 40% of the key professionals, including Team Leader as permanent employees.
- Experience in technical assignments in developing countries; preferably India.
- Track record of providing solutions to complex water problems, with specific reference to the last five years.
- Ability to quickly deploy a team (professionals with relevant experience and qualifications) either from the lead organization or through sub-contracting arrangements.

**Consultant Team (For Each package)**

| Sl. No. | Discipline of the Consultant | Minimum Qualifications and Experience | Suggested Man-Months |
|---|---|---|---|
| 1. | Team Leader/ Senior Hydrologist/ River Basin Modeller | 1. Master's in Hydrology, Hydraulic and / or Water Resources engineering.<br>2. At least 15 years working experience in water resources.<br>3. Having sound knowledge and experience of handling optimal water allocation using multi-reservoir simulation.<br>4. Should have handled at least two projects as a Team Leader/Dy. Team leader in projects in water resources. | 11 |
| 2. | Hydrologist/ River Basin Modeller | 1. Master's degree in Hydrology, Hydraulic and / or Water Resources engineering.<br>2. At least 10 years working experience in water resources modelling<br>3. Preferably having sound knowledge and experience of handling optimal water allocation using multi-reservoir simulation. | 17 |
| 3. | IT Specialist-1 | 1. Graduate in Engineering in Computer Science/IT/Engineering/MCA<br>2. Minimum 7 years of experience in the development and maintenance of software application in science and engineering, web design and management<br>3. Extensive experience in scripting using Java or other similar related tools<br>4. Experience in statistical inferential model development and application would be an asset<br>5. Working experience in development of software related to water resources would be preferred | 6 |
| 4. | IT Specialist-2 | 1. Graduate in Engineering in Computer Science/IT/Engineering/MCA | 9 |

| | | | |
|---|---|---|---|
| | | 2. Minimum 5 years of experience in the development and maintenance of software application in science and engineering, web design and management<br>3. Extensive experience in scripting using Java or other similar related tools<br>4. Experience in statistical inferential model development and application would be an asset<br>5. Working experience in development of software related to water resources would be preferred | |
| 5. | Technical Support Staff | 1. Engineering Graduation in any discipline with minimum 3 years of working experience<br>2. Preferably having working experience in assignments of similar type | 11 |

**12. Duration of Consultancy**

24 months including operation and maintenance period of 12 months

## Annexure-1 to Attachment-1.

# KEY FEATURES OF THE DASHBOARD

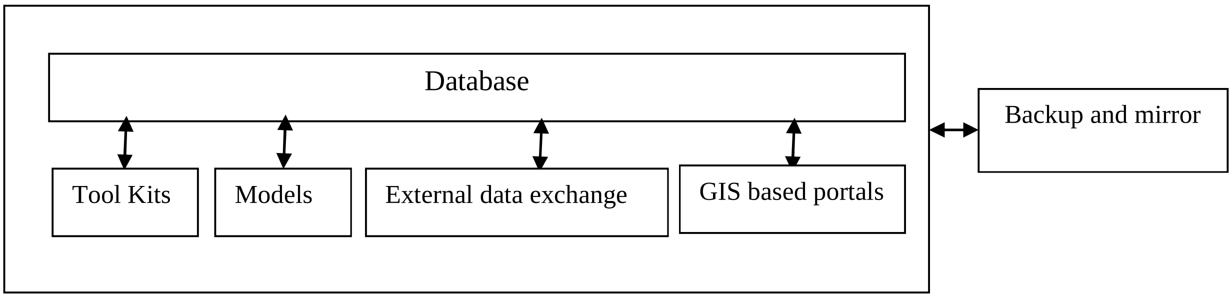
### PURPOSE

The main purpose of the proposed dashboard is to enable search and retrieval of the input data from the eSWIS database, as well as to store results of selected scenarios in the database for future references. It is acknowledged that both the selected model and the eSWIS database have their plotting and statistical analyses tools that will continued to be used. The proposed dashboard will automate the process of searching and retrieving the necessary time series data required to run the model as a planning tool and to disseminate the results. This template for interaction between the model and the database in planning mode will be replicated as much as possible once the Early Hydrologic Prediction Project (EHP) has been completed, which would enable the use of the model as a seasonal operational tool that relies on seasonal runoff forecasts that will be available from the EHP project.

### MAIN DASHBOARD UTILITIES

The following functions may already be available by the selected tool, but if they are not, their development should be included in the project:

- Ability to view all elements of the river system included in the model (river reaches, reservoirs, irrigated areas and other industrial or municipal water users, diversion channels and hydro power plants) on a schematic displayed as a layer on top of a digital map. The user should be able to select any of the components in the active schematic layer and view the input data or the simulated output series for any selected scenario.
- Ability to add/delete various user nodes like irrigation, reservoir, industrial and domestic demands, environmental demands, diversion structures, water bodies, hydropower or other model components.
- Ability to change various demand and supply time series, change water sharing policies or allocation priorities assigned to various stakeholders
- Ability to incorporate reservoir operating rules or optimize reservoir operation based on user supplied priorities and objectives
- Data import and export features between the model and the eSWIS database using the common formats like excel, text, xml, mdb, etc. This includes the ability to communicate with national database via web services for import and export of data. This may include ftp exchange, web service, http web crawlers, or other web queries between the dashboard and India-WRIS / e-SWIS as generally depicted below:



# Dashboard

**FLEXIBILITY**

- Flexibility of the dashboard to apply on more basins (other than the scope of current consultancy) in India. Comprehensive documentation should be provided to enable the client to replicate the dashboard for other basins without any technical support from consultant.
- No need for additional license for installing on multiple servers, national or local server, different servers for other basins
- Ability to host large number of simultaneous users, subject to hardware capacity constraints
- Support for upgrade of software for a period of 5 years after completion of warranty period without any additional cost to client. The support would include upgrades, bug fixes, updates to operating systems etc.

**TOOLKIT**

The following features need to be developed if they are not already available within the selected modeling platform:

- A tool kit for processing time series data (features like converting from hourly daily to monthly, seasonal, annual etc.) should be developed.
- Development of various time series products like conversion to flow duration curves, development of dependable, dry, wet normal year time series from historical records
- Plot and analyze multiple time-series, including historic and simulated flows and reservoir levels for selected periods in time series or probability (flow duration) format.
- Statistical summaries of model performance: this includes tabular presentation of water supply deficits for a single water use component for all time intervals, or for a group of selected components on an annual basis, and parallel statistical analyses of flows are reservoir levels by comparing their statistics like averages, medians, standard deviations, etc.
- Tool kit for unit conversion, to enable on the fly unit conversion for various data series like distance, flows, volumes, temperatures, depths, velocities, rates, pressure, times, weights etc)

**SYSTEM AVAILABILITY**

- All the features described above should be available to online users by using just a browser without any requirement to install software or license on local computer.
- The user should have flexibility to install a local copy of dashboard for offline generation of scenarios, training, hands-on practice
- The user should have option to either utilize national database for offline installation or replicate national database on local computer for offline development of scenarios

***Attachment 2***

# Development of the Model Evaluation Test for Narmada River basin

**Compiled by TMAC Consultant with assistance from NAC staff**
**March 2018**

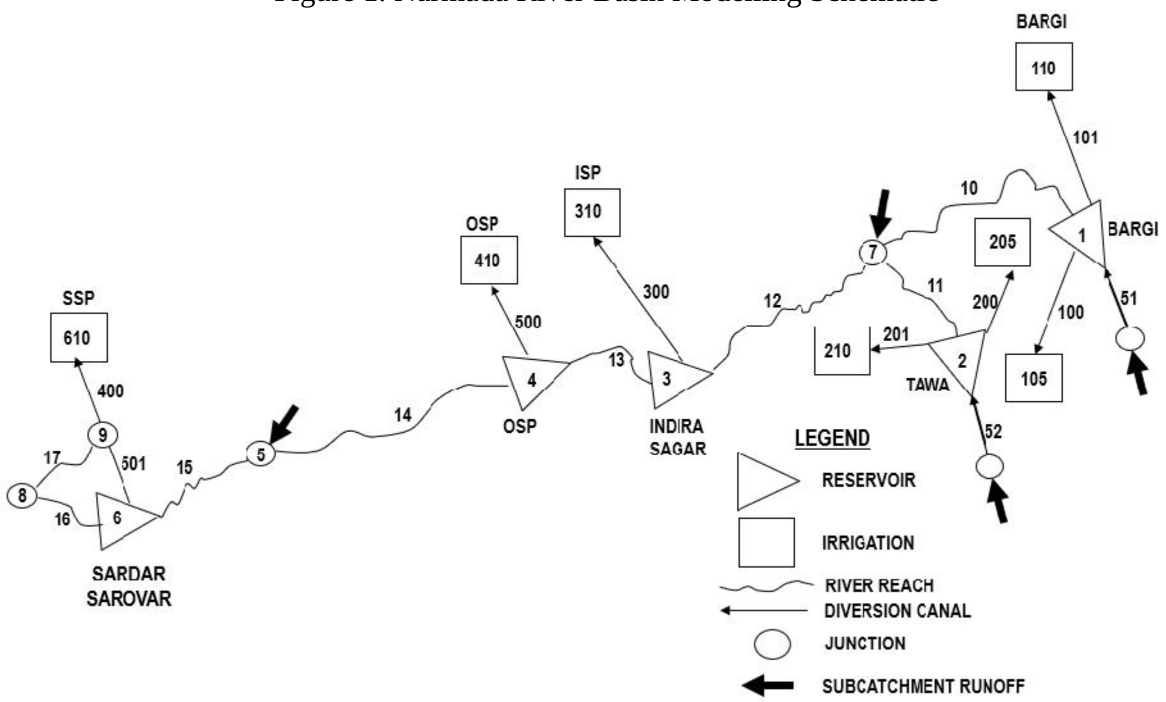
# TABLE OF CONTENTS

# INTRODUCTION

Narmada Control Authority (NCA) has approached the National Hydrology Project (NHP) office in Delhi with a request for assistance in setting up a water accounting model for the Narmada River Basin. The rationale for this was to modernize water accounting which is currently conducted by using spreadsheets, and in addition to water accounting, possibly use other benefits of modern computer modelling tools developed for river basin planning and management. It was decided to conduct the final selection of the model of choice for future use in the Narmada River Basin by first setting up one or more test case scenarios, and identifying suitable models by evaluating their solutions from the standpoint of their ability to meet the stated operational objectives.

A simplified version of the Narmada River Basin is represented by a modelling schematic shown in Figure 1. This schematic includes only the largest structures in the river basin. The total storage of four out of five major reservoirs shown in Figure 1 is about 27 billion $m^3$. NAC has provided historic water levels, diversions and river outflows, along with the evaporation and precipitation estimates. Other necessary data included elevation-area-capacity curves for storage reservoirs. All of the above data were processed and used to create input data series for the test runs.

Figure 1. Narmada River Basin Modelling Schematic




The modelling schematic in Figure 1 shows a list of components and their connectivity. Flow links connect downstream and upstream nodes, which can be either reservoirs, irrigation blocks or simple junctions which are used to join flows from two or more tributaries or split flow at the point of diversion from a river reach into a diversion canal. Reservoirs model storage, releases, and net evaporation losses. Irrigation blocks model consumptive water use.

# 1 MODEL INPUTS

There are four types of data required for river basin models:

- Physical data related to the hydraulic structures included in the model;
- Hydro-Meteorologic data series;
- Water Demand Data; and,
- Operational / management data which define modelling objectives.

Each of the above inputs are important for setting up the model. They are briefly discussed in the following.

## 1.1 PHYSICAL MODEL DATA

The physical data refer to storage capacities of reservoirs as well as flow capacities of diversion channels. They may also include outflow vs elevation curves of spillways or bottom outlets, assuming all operational gates are fully open such that the outflow represents the maximum achievable given the average storage over a time step.

The other important aspect of the physical model data is the network definition. The model requires a flexible definition of the system configuration, which represents the way all components are connected. This defines the flow direction for every channel in the network and enables users to include or exclude additional components such as river reaches, tributaries or reservoirs, which is achieved by merely changing the input data file, without having to change the modelling tool itself.
Elevation-area-volume curves of the Narmada River basin reservoirs included in this modelling test have been restructured to have no more than 20 points, while still integrating to representative volumes and areas for key reservoir operational levels. They are provided in a separate document which contains the rest of the input data.

## 1.2 HYDRO-METEOROLOGIC DATA SERIES

The most important hydrologic input includes the estimates of runoff at locations that are designated with a short dark arrows in Figure 1. Water accounting typically does not involve rainfall-runoff modelling, but rather uses flows and reservoir levels that had been previously recorded and processed by water monitoring agencies. Inflows that are given to the model may represent inflow forecasts over a specified time horizon, or they may represent historic or stochastic estimates of runoff originating from each of the sub-catchments into which a river basin has been previously sub-divided as part of the required model setup.
There are four inflow series developed for the Narmada River Basin study. The most upstream inflows are at Bargi and Tawa reservoirs. They were obtained by running the reservoir balance by using historic storage levels and outflows, and they represent runoff into the reservoirs. Additional smaller reservoirs and water use located upstream of Bargi and Tawa were ignored in this study.
Local runoff over the part of the catchment delineated between Indira Sagar Project (ISP, shown as node 3 in the Schematic in Figure 1) on the downstream end, and on the upstream end with Bargi and Tawa reservoirs is shown as inflow into node 7. The input data file provides complete

natural flow at node 7. The local inflow should be calculated by subtracting Bargi and Tawa inflows from the natural flow at node 7. Most river basin management models are able conduct this subtraction internally within the model. Alternatively, users can conduct this subtraction as part of their input data file preparation. Similarly, runoff between Indira Sagar and Sardar Sarovar Project (SSP) is calculated as the difference between the natural flow at node 5 (located immediately upstream of SSP) and natural flow at node 7, which represents the virgin flows at the location of the ISP dam.

NCA provided time series of historic precipitation and evaporation estimates for each of the reservoirs. Those were initially provided in the units of volume, and subsequently converted to mm, such that they can be applied to water surface areas that are implied by the model during simulations. Evaporation losses on most of the reservoirs in Narmada Basin are substantial. Hence, one of the model features that will be evaluated in this study is the ability of a model to include reasonable estimates of net evaporation. This verification can be done by conducting manual calculation for selected time intervals where the input net evaporation in mm can be applied on the average water surface area that corresponds to the average water level for a given reservoir for a selected time step. The results of manual calculation can then be compared with the model output. All model vendors are expected to provide reservoir evaporation as part of their completed model output summaries.

## 1.3 WATER DEMAND DATA

Future water requirements estimated by NCA were provided as input into the test runs. In addition to this, mandatory flow releases were assessed as a fraction of natural flows for channels 10 and 11 (outflows from Bargi and Tawa, respectively), channel 12 (inflow into ISP) and channel 15 (inflow into SSP). Reservoir outflows are driven by water demands, which are a combination of downstream mandatory releases and consumptive use requirements.

## 1.4 OPERATIONAL DATA

### 1.4.1 Simulated Time Steps

Simulations are to be conducted using 10-daily times steps for the hydrologic year that begins on July 1st of each simulated year and ends on June 30th of the following year. Input data are given in units of volume, which gives the users a choice to decide what length of time steps to select. This is a flexible approach since some models take into account the leap years and some do not.

### 1.4.2 Key Storage Elevations

The primary purpose of modelling river basin operation is to find the best way to operate the available storage reservoirs so as to meet the stated objectives. However, there are operational constraints that models must take into account when searching for the best set of reservoir releases. These include the limits on the available storage, canal capacities and demands, as well as the stated operational goals, which are typically related to the deficit sharing policy among various components that should be implemented in periods of water shortages. Since the test runs involve estimates of future water demands, it was assumed that diversion canal capacities are able to handle the periods with the highest demands. Hence, there are no flow restrictions on the canal capacities that could limit supplies to irrigation demands in any simulated time step (i.e. modellers can assume large flow capacities on the diversion channels that supply water to irrigation blocks).

The existing reservoirs have several key target elevations included in the model. These elevations define dead storage, conservation storage (full supply) and flood control storage (maximum water level), and they are the same for all four simulated test scenarios. The assumed key elevations are listed in Table 1.

Table 1. Key Reservoir Elevations used in the test runs

| Reservoir | Maximum Water Level (m) | Full Supply Water Level (m) | Dead Storage Water Level (m) | Minimum Water Level (m) on June 30th |
|---|---|---|---|---|
| Bargi | 425.70 | 422.76 | 406.00 | 409.00 |
| Tawa | 356.66 | 355.40 | 334.24 | 336.45 |
| Indira Sagar (ISP) | 263.35 | 262.13 | 243.23 | 245.00 |
| Omkareshwar (OSP) | 199.62 | 196.60 | 196.60 | 196.60 |
| Sardar Sarovar (SSP) | 140.21 | 138.68 | 110.64 | 110.64 |

The target volume at the end of the hydrologic year on June 30th is aimed to ensure that there is sufficient storage to meet demands for the first two weeks of the monsoon season in case the start of the monsoon is delayed. It is up to the model to find the best way to reach these target elevations at the end of the dry season. A simulated elevation below the target level for June 30th would be considered a failure to meet the required test problem constraints.

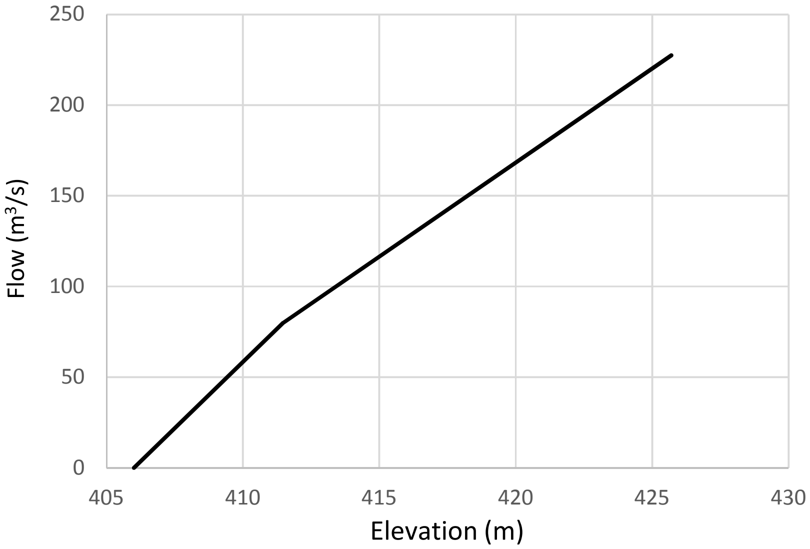
The OSP project was designed primarily as a hydro power generation facility. Consequently, its level is kept at 196.60 m at all times except during catastrophic flood events when its flood control storage zone that ranges up to 199.62 m may have to be utilized to help reduce downstream flooding.

### 1.4.3 Bargi Reservoir Outflows

There are two diversion canals from Bargi reservoir, as shown in Figure 1. The left canal has a sill that is just over 6 meters below the sill of the canal on the right side, which is located at the elevation of 406 m. Since the simulation runs involve the policy of equal deficit sharing in space and time between the water use from the right and the left canal, restricting the flow in the right canal due to elevations that are close to 406 m would also affect water supply in the left canal.

The model should be able to address the question of lower outflow capacities into the right bank canal if and when the water level is approaching 406 m. A conservative assumption was made that some of the available gates are not operational due to maintenance or unexpected failure. This creates a good foundation to investigate the model's behaviour under constrained outflow conditions, especially since this is a dynamic constraint where maximum reservoir outflow is a function of storage. As the storage level drops, the outflow capacity through the right bank canal also drops. To preserve water supplies to the right canal, inclusion of an outflow vs elevation constraint for it should generate model solutions that retain a bit more water in storage than the simulation that ignored this constraint. It is therefore left to the model to decide how far to lower the storage levels so as to maximize overall supply to both blocks. The outflow vs elevation relationship assumed for the right bank canal is presented in Figure 2.

Figure 2. Assumed Maximum Outflow vs Storage Levels for Bargi Right Canal




| Elevation (m) | Flow (m3/s) |
|---|---|
| 406.00 | 0.00 |
| 411.48 | 80.00 |
| 425.70 | 227.44 |

### 1.4.4 Flood Management

River basin models are typically used for studying reservoir operation within the normal flow regime. With time steps that are usually weekly or 10-daily, they are not suitable for studying detailed flood management. However, operating rules often involve reservoir drawdowns during the monsoon period when the likelihood of flooding is high, and as such, pre-flood drawdowns should be integrated within the overall concept of developing reservoir operational rules. To achieve this, flood management should be included in a river basin management model. A typical way to do this is to define full bank flow capacities for critical river reaches where flooding can cause significant damage, and operate the reservoirs within the model such that the flows that exceed the full bank capacities are minimized. The following flow limits have been identified as full bank flow capacities in the Narmada River basin test runs (channel numbers refer to the river reaches in Figure 1):

Channel 10 (outflow river reach from Bargi Reservoir): 4000 $m^3/s$
Channel 11 (outflow river reach for Tawa Reservoir): 2800 $m^3/s$
Channel 15 (inflow into Sardar Sarovar Reservoir): 7600 $m^3/s$

The model of choice should be able to handle the objective to keep flows within the above limits on these reaches whenever possible.

### 1.4.5 Mandatory Outflows

There are various reasons why mandatory outflows should be requested from reservoirs. They could be related to environmental flow targets, or to water sharing agreements between the upstream and downstream states. Without mandatory outflow requirements, river basin models often produce zero outflows from reservoirs into downstream river reaches during low flow seasons, since conservation of storage is one of the default goals built into most models.

Mandatory outflows have been created for the purpose of the test runs for channels 10, 11, 12 and 15, and they are provided as mandatory in-stream flow targets as part of the model input data set. They were developed using guidelines based on the fraction of the respective four natural (virgin) flows developed for the upstream end of those channels. The fractions of those natural flow series were varied between 0.1 and 0.3 based on the time of the year.

# 2 MODEL TEST SCENARIOS

Model scenarios are based on 10-day time steps (i.e. 36 time steps per year). They are set up and evaluated on the basis of following the operating rules outlined below. Simulations begin on July 1st and end on June 30th of every simulated year.

## 2.1 RULES RELATED TO RESERVOIR OPERATION

Reservoir levels should be between the top of dead storage zone and the top of conservation zone (full supply level in Table 1) at all times except during extreme flood events, when the flood storage zone can be utilized between full supply and the maximum level only in those time steps when one of the downstream channels has flow that is equal or greater than the full bank flow capacity.

Reservoir levels should end the hydrologic year on June 30 of each simulated year with a level that is equal or greater than the designated minimum storage levels defined in Table 1.

The highest priority imposed on the reservoirs is to manage flow releases that minimize overbank flooding. The second highest priority is to maintain environmental flow targets for designated river reaches. The third priority regarding reservoir releases is to maintain desired irrigation supply.

Net evaporation losses given in mm in the input data files should be applied to the water surface areas that correspond to the storage volumes derived by the model for each modelled time step.

Reservoir operation is conducted with a single year forecast, i.e. the starting levels and a series of 36 forthcoming inflows and demands are considered to be known, thus covering a period of 365 days of the assumed forecast of demands and inflows. The model is tested on a set of 9 years and each of them is solved individually, with full foreknowledge of the hydrologic conditions within a year, but without any knowledge of the hydrologic conditions in subsequent years. Hence, it modelling is set up to optimize more than one time step simultaneously, the simultaneous simulation with optimization should not exceed 36 time intervals.

Bargi reservoir releases are made only for the designated environmental flows immediately downstream of Bargi reservoir (channels 10 and 12), and for supply of two irrigation blocks (105 and 110 in Figure 1). All other surplus flows are kept in storage with the exception of spills, which are occasionally inevitable. Bargi reservoir will only assist the downstream reservoirs during extreme flood events by allowing its flood control zone to be filled in an effort to keep the downstream flows within the full bank capacities on all channels that are affected by the Bargi reservoir releases.

The same rules are in place for the Tawa reservoir, which only releases its storage to its designated environmental flow channel and its irrigation blocks, with the exception for extreme flood events, where it is expected to assist in keeping flows within the full bank capacities (if possible) on all downstream channels affected by the Tawa reservoir releases.

ISP reservoir releases are made to manage floods and environmental flow targets in channel 15, as well as to supply water to irrigation blocks 310 and 410 shown in Figure 1. SPP reservoir releases are made to support environmental flow targets in channel 17 as well as irrigation block 610.

### 2.2 DEFICIT SHARING RULES AMONG IRRIGATION BLOCKS

The following rule applies to all modelling scenarios: if irrigation deficits are inevitable due to insufficient water availability, the relative deficits expressed as a fraction of water demand in every time step must be shared evenly for all time steps within a year. The model should minimize the deficits over the entire hydrologic year, and find the reservoir operation that will achieve the minimum deficits for each modelled hydrologic year. Sharing deficits in time implies that the relative deficits remain the same for all time steps within a year for a given irrigation block or for two blocks supplied by the same reservoir, if there is additional sharing among the blocks that are supplied from the same storage reservoir. Relative deficits are expressed as:

$$Rd = \frac{Dt - Qt}{Dt}$$

Where Dt is water demand in time step t while Qt is the supplied quantity of water within the same time step.

### 2.3 OBJECTIVE FUNCTION

An objective function can be calculated and its values used to compare different model solutions. Objectives can be based on calculating the assumed monetary loss for undesirable flow conditions. Although selected arbitrarily in this exercise in order to test model's capabilities, monetary loss associated with flooding can be assessed and expressed as the sum-product of the assumed flood damage and the excess overbank flow. For example, it can be assumed that 1 $m^3/s$ of flow above the full bank capacity causes $1000 worth of damage in any channels where flood control is to be managed by the model (channel 10, 11 or 15). For models that derive solutions in the units of flow, the objective function related to flooding of channels 10, 11 and 15 can be expressed as:

Objective Function$_f$ = OF (F) =

$$\text{Min} \sum_{t=1}^{t=36} \{\$1000[\max(Q_{15}(t) - 7600, 0) + \max(Q_{10}(t) - 4000, 0) + \max(Q_{11}(t) - 2800, 0)]\}$$

The above is the objective function related to reducing flood damage (hence the subscript f in "Objective Function$_f$". Similar expression can be applied to reducing failure to meet environmental flow targets $T_i(t)$as in Objective Function$_e$, but with a lower priority factor of \$100 instead of \$1000 per unit of flow summed over 36 time steps, i.e.

Objective Function$_e$ = OF(E) =

$$\text{Min} \sum_{t=1}^{t=36} \{ \$100 [\max( T_{10}(t) - Q_{10}(t), 0 ) + \max( T_{11}(t) - Q_{11}(t), 0) + \max( ( T_{12}(t) - Q_{12}(t), 0) + \max( ( T_{15}(t) - Q_{15}(t), 0)]\}$$

The selection between zero and the difference between the target and the achieved flow is necessary since the achieved flows can sometimes be higher than the target flows during the monsoon period when reservoir is spilling, while the purpose of the above expression of the objective function is to minimize deficits that are defined as flows below the target.

Finally, the third component of the objective function is related to the failure to meet the specified irrigation demand Di(t). It is written as a sum-product of the loss of \$10 per unit of deficit flow for all components over all 36 time steps:

Objective Function$_i$ = OF(I) = $\text{Min} \sum_{t=1}^{t=36} \sum_{i=1}^{i=7} \{ \$10 [D_i(t) - Q_i(t)]\}$

Since the flows to an irrigation block and never greater than the target $D_i(t)$, there is no need to use the max{0, $D_i(t) - Q_i(t)$} function in formulating this part of the objective function. The ultimate objective function is the sum of the three constituents related to flood, environmental flows and consumptive use, i.e.

Minimize { OF(F) + OF(E) + OF(I) }

The above objective function is a measure of model performance represented by a single number for each simulated year, equal to the total of the three objective functions components. However, the above approach is valid only if none of the stated constraints have been violated. Evaluation of model results will therefore first focus on making sure that none of the constraints have been violated. The Objective Function values can be compared only after successful verification of this condition.

## 2.4 SCENARIO DEFINITIONS

The following configuration is valid for each scenario:

Scenario 1

Bargi Reservoir releases are driven by environmental flows in channel 10, and irrigation requirements on blocks 105 and 110. These two irrigation blocks are expected to share deficits evenly in time and in space within each year in all scenarios. During high floods, Bargi storage will be operated to help reduce flows in any of the downstream channels (10 or 15 in this scenario) such that overbank flooding is minimized. Storage levels above the normal water levels are allowed only during time intervals when the full bank capacity is reached or exceeded on either or both of channels 10 or 15.

Tawa Reservoir releases are driven by environmental flows in channel 11, and irrigation requirements on blocks 205 and 210. These two irrigation blocks are expected to share deficits evenly in time and in space. During floods, Tawa reservoir storage will be operated to reduce flows in the downstream channels 11 or 15 and minimize overbank flows. Storage levels above the normal water levels are allowed only during time intervals when the full bank capacity is reached or exceeded on channels 11 and 15.

Indira Sagar Reservoir (ISP) releases are driven by environmental flows in channel 15, and irrigation requirements on blocks 310 and 410. These two irrigation blocks are expected to share deficits evenly in time and in space within a year. During floods, ISP storage will be operated to help reduce flows in downstream channel 15 such that overbank flows are minimized. Storage levels above the normal water levels are allowed only during time intervals when the full bank capacity is reached or exceeded on channel 15.

Sardar Sarovar Reservoir (SSP) will first provide environmental flow targets of 17 $m^3/s$ for channel 17 at all times, and then provide flows for its irrigation block 610. If deficits are inevitable in irrigation block 610, they should be shared evenly in time over the 36 time intervals.

Note that in Scenario 1, there are no environmental flow targets for channel 12, so that channel should be ignored when evaluating the value of the objective function listed in the previous section.

<u>Scenario 2</u>

Scenario 2 is the same as Scenario 1 with one notable exception: in addition to meeting their environmental flow targets on their respective outflow channels 10 and 11, reservoirs Bargi and Tawa have a shared responsibility to meet environmental flow targets on Channel 12. The model should decide how much each reservoir contributes in each time step to meet the environmental flow targets at channel 12.

<u>Scenario 3</u>

Scenario 3 is the same as Scenario 1 with one important change: the outflow vs elevation curve defined in Figure 2 is applied on Bargi Right Bank canal (diversion channel 101 in Figure 1). The model must determine minimum storage for each time step within a year by balancing the outflow constraint on the right diversion canal with the constraint to spread deficits evenly in time and among the two irrigation blocks throughout the year. As a result of those two constraints. The minimum operational storage is 406 m throughout the year, except on June 30$^{th}$, when the minimum storage level should be greater than or equal to 409 m.

<u>Scenario 4</u>

This scenario is a combination of Scenarios 2 and 3. It has environmental targets for Channel 12 as in Scenario 2, and there are also limitations on the outflow from Bargi storage during periods with low water levels due as defined in Figure 2. Irrigation blocks 105 and 110 share the same deficit over all time intervals with each simulated year. The minimum operational level is 406 m and the minimum required storage on June 30th is 409 m.

Solutions to Scenarios 2 and 4 defined in this document are mandatory, as they are more technically challenging. Solutions to Scenarios 1 and 3 are optional.

### 2.5 DESIRED MODEL OUTPUT FORMAT

Some models work in the units of volume, while others use the units of flow. Among those that use flow units, there are models that take into account leap years and those that ignore leap years. Hence, to avoid conflicting situations, time series hydrologic and water demand input data for this test run are provided in the units of volume, such that the users can convert them to the appropriate flows based on the length of the time steps that their models can handle. Model solutions should be provided both in the units of volume and the units of flows in a single column output format for each component shown in the modelling schematic in Figure 1. The components should be grouped by reservoir in a downstream progression (i.e. Bargi, Tawa, ISP, OSP and SSP). The reservoir output should include storage levels at the end of each time interval as well as net evaporation loss for every time interval. All components in the schematic should be included in the output, except for the diversion channels, since their values are the same as the irrigation blocks. The client may provide a template for model output to be filled by the prospective vendors.

# 3 EVALUATION OF MODEL RESULTS

Model results will be evaluated first with respect to their compliance with the constraints associated with each modelling scenario. Once it has been established that model solutions do not violate constraints, model evaluation will progress to compare the values of the objective function for each simulated year.

### 3.1 EVALUATION OF MODEL CONSTRAINTS

Compliance of model solutions with constraints is a mandatory requirement expected from all models to warrant further evaluation of their performance. The following constraints should be satisfied for each modelling scenario:

#### 3.1.1 Mass Balance Constraints

This constraint ensures that the sum of all inflows and all outflows into a node are equal. For junction nodes, this refers to the sums of the flows in all incoming and outgoing channels for a node (a small deviation on the third decimal in the model output is allowed if the model outputs are printed with three decimals). For reservoir nodes, the balance equation must also include storage change in addition to the sums of inflows and outflows. In general, storage change is defined as:

$$\frac{\Delta V}{t} = \frac{Ve - Vs}{t} + \frac{(E - P)[A(Ve) + A(Vs)]}{2t}$$

where:

| | |
|---|---|
| $V_e$ | volume at the end of time step $t$ ($m^3$) |
| $V_s$ | volume at the start of time step $t$ ($m^3$) |
| $P$ | total precipitation over time step $t$ (m) |
| $E$ | total evaporation from the reservoir surface over time step $t$ (m) |
| $A(V_e)$ | surface area ($m^2$) corresponding to the ending volume $Ve$ |
| $A(V_s)$ | surface area ($m^2$) corresponding to the starting volume $Vs$ |

In the above formula, net evaporation is applied on the average water surface area over a simulated time step. Some models apply net evaporation at the beginning and some at the end of the time step. Model vendors should provide a short summary that explains how their model calculates net evaporation and explain how net evaporation is included within the framework of the optimization algorithm used by the model.

### 3.1.2 Storage Limits Constraints

Storage output from the model should be within the full supply and dead storage limits provided in Table 1 for all time intervals except for the time interval that ends on June 30$^{th}$ (the last time interval in each simulated year), when the ending storage should be equal or greater than the minimum storage for June 30$^{th}$ provided in Table 1.

Storage above the full supply level can happen only during floods when the channel flow in one of the downstream channels is either at or above the full bank capacities. The maximum storage limit should not exceed the maximum values provided in Table 1.

### 3.1.3 Environmental Flow Constraints

Only the environmental flow in channel 17 must be included in the model as a hard constraint, with a flow target of 17 $m^3/s$ that should be met at all times. Other environmental flow targets on channels 10, 11 and 15 vary throughout the year and they should be met for all time steps if possible. They form part of the modelling objectives for each scenario.

### 3.1.4 Consumptive Use Constraints

Consumptive use constraints represent the upper limit on water supply that should be provided in each time step. The model should limit water supply to any irrigation block in the system based on the target demand which is provided in the input data file for each irrigation block and each time interval.

## 3.2 EVALUATION OF MODEL OBJECTIVES

Vendors should provide the value of the objective function for each of the 9 simulated years and for each of its three constituents in a separate column (flood damage, failure to meet the environmental flows, and failure to meet irrigation demands). The users should present the values of the resulting objective functions in the following format shown in Table 2 below:

Table 2. Objective Function Evaluation Table

| Year | Objective Function Values | | | Total |
|---|---|---|---|---|
| | Flooding | Environmental Flows | Irrigation Supply | |
| 2008 | | | | |
| 2009 | | | | |
| 2010 | | | | |
| 2011 | | | | |
| 2012 | | | | |
| 2013 | | | | |
| 2014 | | | | |
| 2015 | | | | |
| 2016 | | | | |

The formulas for calculating the values in Table 2 are given in Section 2.3. The total is the sum of all three constituents of the objective function. This table should be provided for model results both in the units of flow and the units of volume, with a note on the length of the assumed time steps.

Failure to meet the expected feasibility constraints involves checks on the stated flow limits and mass balance equations that may be encountered at any node or in any simulated time interval. The formulas for calculating compliance limits in the feasibility check table are typically calculated as a relative deviation from limits given in the problem description. In particular:

- Simulated values are compared to the target values in the case of reservoir target levels (full supply, dead storage or maximum level during floods). An exceedance of more than 0.01 m above the prescribed operational limits will be considered a failure.
- Bargi Reservoir outflow limits for diversion channel 101 are compared to the maximum possible outflow limits as a function of average Bargi reservoir levels over a simulated time interval. The outflow limit function is given in Figure 2 of the Narmada RBM Evaluation Test document. An exceedance of outflows of more than 5 % above the limits defined by this curve will be considered a failure.
- Due to the different ways net evaporation is calculated within various models, the expected tolerance limit is 2% for the difference between the cumulative net evaporation over 9 years produced by the model compared to the results of the manual calculation. The manual calculation will be based on the use of the average area over a simulated time step multiplied by the net evaporation in mm used as input data in each simulated time step.
- Deficit sharing constraints are to be spread evenly within a year for each irrigation component, and also among the components that are aimed to share deficits. The implies that relative deficits are equal for all simulated time steps within a year. Also, there are three pairs of irrigation blocks that share the same relative deficits for all simulated time steps: 105 / 110, 205 /210, and 310 / 410.
- Mass balance constraint should be verified on every node of the modelling schematic in Figure 1. Clients will use the output in the units of volume provided by the consultants to verify this claim (bidders are requested to provide model output both in the units of volume

and in the units of flow). Reservoir net evaporation calculated by the model should also be provided in both units of flow and volume. Any imbalance between all inflows and all outflows for a node that is greater than 0.01 m3/s will be considered a violation of constraints.

Vendors should focus on Scenario 2 and Scenario 4, which will be used to evaluate model comparisons, and ensure that all constraints are met. Both tables used for verification of constraints and for calculation of the objective functions will be used in model evaluation. The models are expected to minimize the cost of having all deficits, while simultaneously complying with the model constraints defined in the Narmada RBM Evaluation Test document. Table 3 shows the expected feasibility checks criteria that should be verified by the consultant.

Table 3. Feasibility Check Criteria

| Year | Time Interval | Feasibility Check Table | | | | | Total Number of failures |
|---|---|---|---|---|---|---|---|
| | | Compliance with storage limits | Compliance with reservoir outflow limits | Accuracy of Reservoir Evaporation (% error compared to manual calculation) | Compliance with deficit sharing constraints | Compliance with mass balance constraints | |
| 2008 | 1 | | | | | | |
| 2008 | 2 | | | | | | |
| 2008 | 3 | | | | | | |
| . | . | | | | | | |
| . | . | | | | | | |
| 2009 | 1 | | | | | | |
| 2009 | 2 | | | | | | |
| . | . | | | | | | |
| . | . | | | | | | |

### 3.3 OTHER MODEL FEATURES

In addition to the solution of the technical problem, vendors should include a description of other model features. The following features are considered important:

<u>Flexibility</u>: describe the model options related to the flexible configuration of the river basin network and the available time step length options.

<u>Model components</u>: list all component types that can be included in the model.

Model optimization engine: explain the type of algorithm used by the model to find the best basin wide water allocation.

Model constraints: explain types of constraints that can be handled by the model. In particular, with respect to the importance of model application in India, provide a short description of how the following constraints are handled:

- Reservoir evaporation
- Return flows from irrigation and their relation to consumptive use
- Reservoir outflow limits as a function of the available storage
- Specified deficit sharing policies
- Diversion limits (both seasonal and instantaneous)
- Target volumes over specified period as required by the apportionment agreements between the upstream and downstream states

Model Interface: what kind of user interface is available for setting up the input data files and for quick analyses of the model output including graphical and statistical summaries.

Model capabilities to switch from planning to seasonal operations, where planning simulation includes historic data while seasonal operation includes input data based on the existing demand and inflow forecasts. Describe what steps are required to switch from planning to seasonal model runs.

Provide information on licensing requirements and the availability of source code, along with a description of additional existing model features that may be of importance to its applications in India.

## Attachment-3

**The soft copy of input data in excel format can be downloaded from National Hydrology Project Web Site URL**: http://www.nhp.mowr.gov.in/docs/narmadadata.xlsx