Terms of Reference

For

Consultancy Services for Conducting River Behaviours Analysis for Rapti River System in Uttar Pradesh

1. Background:

Annually recurring floods in the Ganga, Yamuna, Ramganga, Gomati, Sharda, Ghagra, Rapti and Gandak rivers in Uttar Pradesh State inundate about 2.7 million hectares, adversely impact more than 21.1 million people and cause INR 4.3 billion damages. More than 30% of the total geographical area of the state is flood prone including 23 districts[1] in the eastern, western and central regions. Recurrent floods are devastating to the state economy and undermine poverty alleviation efforts. Floods affect lives, livelihoods, productivity and the security of existing investments, as well as acting as a disincentive for future investments.

The rivers of Uttar Pradesh are morphologically active, particularly during the monsoon season. During the monsoon season, larger flows causes the deep channels to migrate laterally and erode the banks which poses a threat of serious damage to valuable property, lines of communication, towns and villages.

An understanding of the morphology and behaviour of a river is a pre-requisite for scientific and rational approaches to planning and design of river training schemes. A morphological study seeks to understand the behaviour of a river, that can be manifested in frequent changes of the river course, lateral migration of the channel, heavy out-bank spilling due to inadequate channel capacity, frequent carrying of secondary or new channels, rise in river beds and/or frequent erosion of river banks and embankments.

Morphological studies play an important role in planning, designing and maintaining river engineering structures. In the Rapti River Basin, the rivers have largely been confined between their flood embankments, yet the lateral migration of the rivers continues. This natural lateral migration results in endangering embankments and river training works and often costly anti-erosion works to strengthen and protect these river protection and training works.

Channel morphology is the result of interactions between four broad categories of variables: i) fluid dynamics, which includes velocity, discharge, roughness and shear stress; ii) channel character or channel configuration including channel width, channel depth, channel slope, channel shape and channel pattern; iii) sediment load; and iv) bed and bank materials including composition and character - e.g. coarse, fine or medium.

The satellite imagery based empirical morphological prediction approach provides a viable alternative to complex conceptual models which require extensive field data, though limited currently to annual predictions. Historic satellite imagery, supported by field assessment, provide a

[1]Eastern UP (Gorakhpur, Deoria, Basti, Santkabir Nagar, Siddharth Nagar, Mau, Maharajganj, Shrawasti, Kushi Nagar, Azamgarh, Balia, Gonda, Balarampur & Bahraich), Western UP (Mathura, Agra, Bulandshahar, & Badaun) and Central UP (Lucknow, Sitapur, Hardoi, Barabanki & Raebareli)

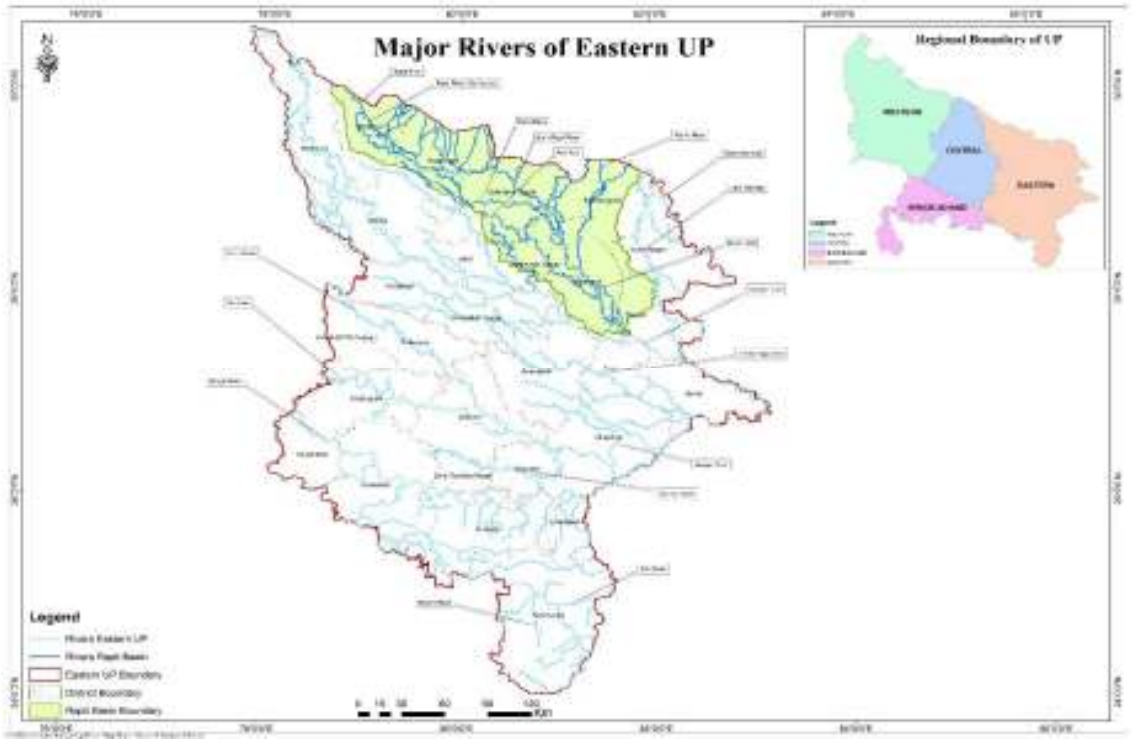
useful information source for mapping river plan form features and tracking rates of change. Multi-temporal satellite image can be analyzed to determine the interaction between deposition and erosion features and flow fields. As new satellite imagery becomes available the results can be updated to reflect the most recent river morphology regime. This type of study is helpful for planning of river training works and anti-erosion control schemes to sustain flood protection as it identifies where erosion is most likely to affect planned structures.

2. Rivers in Rapti River Basin:

a) The Rapti River:

The Rapti River was historically known as Iravati. An Index Map showing the Rapti Basin is given below in **Figure 1.** The river originates in the Siwalik Himalaya of Nepal at an elevation of 3,050m. After flowing through Nepal, it enters Eastern Uttar Pradesh in Chanda Pargana, east of the Kundwa village of Bahraich district. It flows in a very sinuous course with shallow depth and causes heavy flooding in the districts of Eastern Uttar Pradesh (a 1954 inundation map is provided in **Figure 2**). The river then flows through the districts of Bahraich, Balrampur, Shrawasti, Basti and Gorakhpur and joins the Ghaghara on its left bank near Barhaj town of Deoria district **(Refer Figure 1).**

The Rapti River has a total length of about 776 km from its origin to its confluence with the Ghaghra at Barha. Out of this, 290 km lie in Nepal territory. The total catchment area of the Rapti River is 226,400 sq km, out of which 14,500 sq km lies in Nepal.



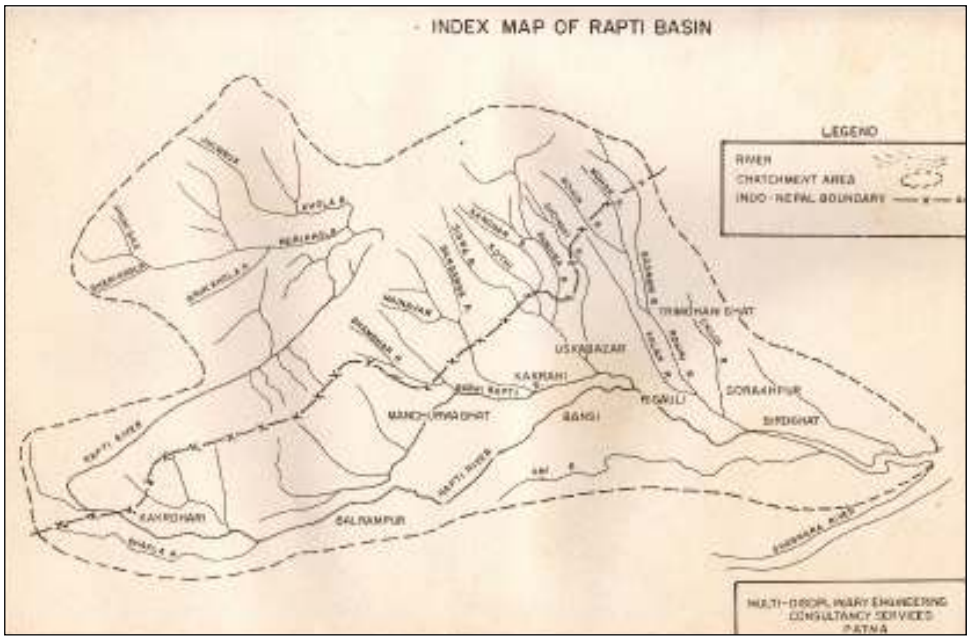


Figure 1: Index Map Showing Rapti Basin

b) Major Tributaries of Rapti River:

After the hair pin bend just above the Indo-Nepal border, the river maintains a south-easterly direction passing through a number of lakes and swamps and some abandoned water courses. The major left bank tributaries are Kain, Burhi Rapti, and Rohini. But those on the right bank are old bends of the Rapti River, with little importance. The Bhakla and the Ami are major among them.

However, Rohini from the left and Ami from the right are the only two important tributaries in the lower reach. The location of each tributary joining the Rapti River can be seen in **Figure 1.**

The Kain: The Kain comes from Tulsipur tarai and is fed by the Hathikund and numerous other streams. The total length of the Kain is 51 km. It joins the Rapti below Bhinga at Lachhmanpur Gurpurwa.

The Burhi Rapti: The Burhi-Rapti may have historically been the main channel of the Rapti. The Burhi Rapti emerges near Mathura, which is situated in the tarai region and flows across Balrampur district in a direction roughly parallel to that of the Rapti River, joining the Rapti River just above Rigauli. The total length of the Burhi Rapti is 95 km. The major tributaries of Burhi Rapti are Banganga, Ghonghi, and Rohini.

The Rohini: This river originates in the tarai region and passes through Maharajganj district. Kalan, Mohini, Basmani and Chillua are its major tributaries. The total length of the Rohini river is 125 km. It joins the Rapti near Gorakhpur city.

The Bhakla: The Bhakla River is the chief affluent of the Rapti. It originates in the tarai region of Nepal and flows for a considerable distance through Bahraich district. The total length of the river is 41 km. It joins the Rapti at Piprahwa near Bhagwanpur.

The Ami: The Ami is a plain fed river. The Reruwa is a small tributary, which joins Ami on its right bank near Banskhor of Basti district. It passes through the large track of paddy lands in Basti, Santkabir Nagar, and Gorakhpur districts. The Barar, an old channel of the Rapti, joins the Ami river in Santkabir Nagar district. The total length of the Ami River is 147 km and joins the Rapti in Gorakhpur district.

c) Gradient of the Rapti River:

The course of the Rapti River can be divided into three sections as shown in **Figure 3**.

The first section is mountainous. In this section, the river runs in a longitudinal valley. It receives the combined waters of Madi, Lungri and Jhirmuk. The altitude drops from 3000m to 1500m and the slope of this section is steep.

The second section of the river is called Rapti Dun. This section of the river flows up to Nepalganj. Here, the river turns south presenting an elbow towards Nepalganj. The altitude of this section varies from 300m to 150m.

In the third section, the Rapti River enters the tarai region of Eastern Uttar Pradesh. In this tarai region, the gradient is very low throughout its easterly. The altitude of this section varies from 100m to 80m. In this section, the Burhi Rapti and Rapti flow parallel to each other for a considerable distance and the doab is marked by flat terrain without any drainage line. The main Rapti River flows close to the watershed that separates it from Bhangar land.

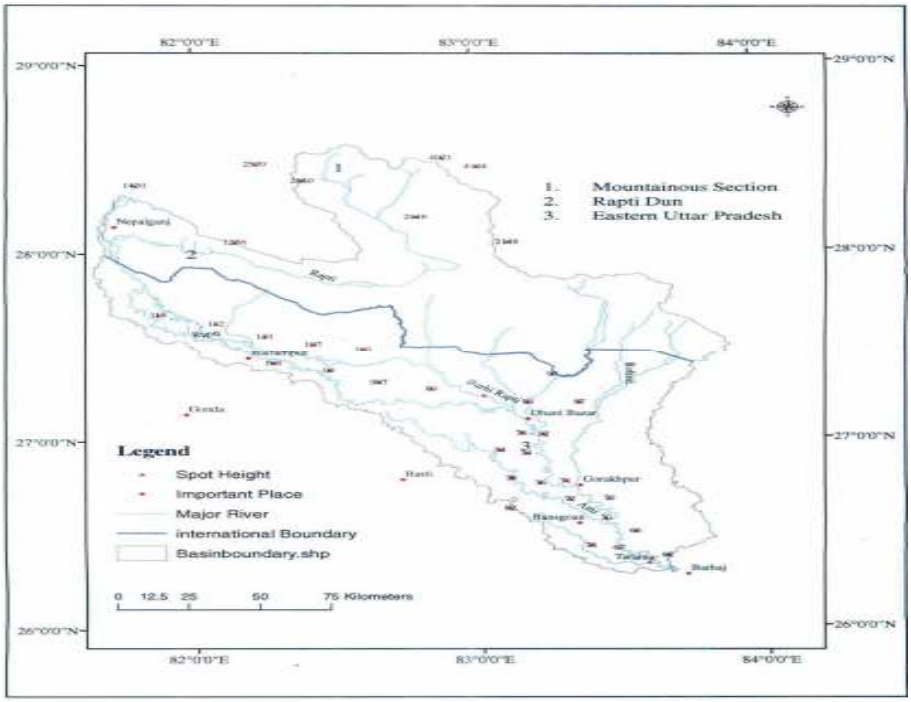


Figure 2: Course Gradient of the Rapti River

3. Morphology of the Rapti River:

The Rapti River is fed by numerous tributaries dropping sharply into the Rapti from Siwalik and its foot hills. The basin is a homogenous plain of older and newer alluvial deposits. High rainfall (mean 1450 mm/year) in the basin's upper catchment Himalayan and the Shiwalik ranges leads to extensive soil erosion and landslides, and every year the river carries an enormous quantity of sediments from its catchments in the mountains. The silt load of the Rapti River is about 15.6 MT/yr. The migration of the Rapti river channel is driven by deposition of these excessive sand loads carried by the river.

4. Objectives

The objective of the river behaviour analysis of the Rapti River in Uttar Pradesh Stateis to understand ongoing morphological processes, to develop a satellite imagery based methodology for predicting futureshort-term morphological changes in the river and their implications for flood management activities including identification of vulnerable existing and planned flood management infrastructure; and prepare user manual, train FMISC & Field engineers for understanding and using the model, and assist in integrating the process and results of the study in the proposed Embankment Asset Management System (EAMS) under a different consultancy.

5. Scope

The study would cover the Rapti main stem and tributaries in the basin in Uttar Pradesh State, and include, but not limited to, the following:

I. Reviewing of internationalliterature and reports of historical morphological development of the Rapti river system under the study including historical and current satellite imagery, and selecting rivers with identifiable morphological changes the Rapti basin for detailed study.
II. Reviewing different models and approaches suitable for predicting morphological behaviour of the river system;
III. Inventorying and evaluating data availability and limitations for the proposed study;
IV. Analyzing available time-series water level, discharge, cross-section and sediment data;
V. Selecting criteria for river bank line delineation based on consultation with UPIWRD and reconnaissance surveys;
VI. Assessing prevailing morphological process and future development of the rivers;
VII. Identifying the long term and short term morphological processes along both banks of the river system
VIII. Developing the methodology framework based on the understanding of the river morphology and the project inception phase;
IX. Assessing the rate and direction of the migration of the river bends;
X. Studying the effects of bank protection structure/s on channel morphology;
XI. Assessing the effect of Rapti Barrage on the river system (pre and post structure conditions);
XII. Identifying important parameters for predicting channel and river morphology;
XIII. Developing a tool/model for predicting river bank erosion and morphological changes including embayment between spurs;
XIV. Identifying vulnerable reaches/locations and giving future prediction one year ahead, based on criteria agreed with UPIWRD;
XV. Developing the GUI driven trend model and its presentation outline;
XVI. Validating of the model in the current flood season;

XVII. GIS mapping for vulnerable locations and database preparation;
XVIII. Assisting in integrating the model and outputs in the EAMS under development in a separate consultancy.
XIX. Developing training and user manuals and providing training to the UPIWRDengineers;

6. Tasks and deliverables

The study should be implemented through the key tasks described below.

Task 1: Literature Review, Data Collection and Review: Review international literature on river morphology analysis methods and select an appropriate approach which uses satellite images as the primary source for assessing river morphology. The consultant will also study the requirements and limitations of data needed for the proposed assignment and elaborate on the present status of data availability. Preliminary analysis of multi-year satellite imagery would be conducted and tributaries with identifiable morphological changes would be selected, in consultation with UPIWRD, for detailed analytical study.

Finally, the consultant will undertake an inception meeting with the department to confirm the project scopeincluding the rivers to be studies, schedule and training plan; collect all available information[2] to inform the river morphology assessment; and review the available data to identify any gaps.

> ***Deliverable 1. Inception report:*** -The inception report will outline the project scope, methodology, schedule, outputs, and training plan.

Task 2-Destkop study stage 1 – Catchment physiography: Sediment transport processes in alluvial systems are heavily controlled by the channel form, flow regime, sediment supply and riparian vegetation condition. For understanding of these factors, a review of physiographic characteristics of the catchment should be undertaken as a first stage of the desktop assessment. This should include review and analysis of: i) the landscape including catchment relief and morphology; ii) geology and soils; iii) riparian and floodplain vegetation; iv) rainfall; v) water resource development (i.e. dams etc.); and vi) historic, contemporary and future changes in land-use

Task 3- Desktop study stage 2 – Fluvial geomorphic categorisation: In the second stage of the desktop study, the consultant will classify the geomorphology of the Rapti River based on satellite imagery, topographic data and other available spatial data (e.g. geology, soils and vegetation). Classifications should include but are not restricted to: i) degree of confinement; ii) plan form; and iii) sediment regime.

> ***Deliverable 2. Report on Physiography and fluvial geomorphic categorisation***: Deliver a report and associated GIS layers which describe the catchment physiography and fluvial geomorphic categorisation of the Rapti River.

Task 4- Desktop study stage 3 – Temporal spatial analysis of satellite imagery: Identify historical changes in channel geometry, plan form and riparian vegetation condition in laterally active reaches

[2] Relevant documents include papers, report and journal articles, historical satellite imagery, discharge data, channel cross-sections, relevant GIS layers, in-stream infrastructure and location of existing and planned flood management assets.

based on multi-year satellite imagery, along with other available information. This will inform a trend assessment of morphological processes occurring in the Rapti River system (i.e. identification of meander migration/extension/translation/rotation, avulsions, cutoffs, widening and aggradations, embayment between spurs). Based on this understanding of morphological processes, and an overlay of flood impact and flood management asset information, priority reaches will be identified where flood management assets are vulnerable to river processes such as bank erosion, channel aggradations and channel degradation.

> ***Deliverable 3*. Report on Morphological Trends, Priority Vulnerable Sites and Training Plan:** Deliver a report and associated GIS layers which classify the broad scale morphological trends and processes of the Rapti River systemand identify priority vulnerable sites where flood management assets are at threat from river processes.
>
> Consultant also needs to submit the Training Plan for providing training to minimum of 6 FMISC / UPIWRD engineers.

Task 5- Morphology modelling for predicting changes: Results from the morphology model, which would be primarily empirical based on parameters observable in satellite imagery, and developed for different river reaches with differing morphological behavior, should be used for prediction of plan form changes (such as extent of river bank erosion, extent of embayment, channel development/abandonment or rate of channel migration within the braided belt), at least a year in advance.

Task 6- Field assessments: Develop a targeted field program based on the desktop analysis and morphological modelling to assess priority vulnerable reaches in more detail. The purpose of the field assessments will be to assess the dominant geomorphic processes and likely trajectory of the river for each reach and assess the implications for existing or planned flood management assets. Geomorphic assessment techniques should be used to observe, record and analyse geomorphic forms and processes, and riparian and in stream vegetation condition and structure. Observations from the aerial photograph interpretation should be ground-trusted during the field assessments.

Fluvial geomorphic field assessment for each reach should be used to: i) identify current and future flood management assets that are vulnerable to channel change including both degradation and aggradations; and ii) identify the likely success or otherwise of erosion control interventions (vegetation or structural interventions).

> ***Deliverable 4 Report on River Morphology Implications for Flood Management***: Deliver a report and associated GIS layers which describes the morphological modelling results, river morphology processes occurring at each priority reach and the implications for flood management planning and infrastructure.

Task 7- Cross-cutting task – Training on river morphology assessments: The consultant needs to provide training on river morphology assessments to enable department staff to refine and update the river morphology analysis whenever new information, such as new satellite imagery, becomes available. The purpose of the training should be to provide participants with a basic grounding in the fundamentals of fluvial geomorphology and waterway management interventions. The training should focus on the geomorphic and waterway issues directly relevant to understanding catchment

and river functions and processes. Training should also include the theory of river morphology, desktop and spatial analysis, field assessments, implications for flood management planning and assets, and design of erosion control structures.

> ***Deliverable 5*:** User Manual, Training Report and Delivery of Model: To develop User Manual for River morphology analysis and to submit Training Report on training provided. Consultant also needs to deliver the developed model to the client.

7. Responsibilities of the consultant

The consultant shall:

- Collect and compile all data (satellite, discharge etc.) supplied from UPIWRD;
- Deliver all tasks and deliverables as described in "Tasks and deliverables", the Team Leader will be responsible to the Chief Engineer, Investigation and Planning, Flood, Irrigation & Water Resources Department, Uttar Pradesh for proper and timely execution of all the activities and submission of the outputs /reports; and
- Work in a coordinated way with the department, in particular with Flood Management Information System (FMIS) Centre and other consultants such as on EAMSworking on the project.

8. Responsibilities of UPIWRD

- Provide all data available with UPIWRD(Cross Section of the River Rapti and four major tributaries, rainfall, discharge and other data) and with FMISC
-), procure identified satellite imagery(LISS-3 Satellite Data for both pre and post flood season for multiple years),and facilitate procurement of other data
- Facilitate field visits, interaction with field units, and collection of field and office data
- Provide computing facility including image processing software and GIS software and office space for analysis if needed in Lucknow.
- Identify and make available UPIWRD engineers including FMIS Centre staff to act as counterpart team.
- Review and approve reports as per schedule for speedy execution of consultancy

9. List of key positions

Name of position	Qualification	Suggested man months
Team Leader - River morphology expert	Postgraduate degree in Geography / Water Resources Engineering or other relevant field At least 10 years' experience in the field of river morphology assessments	4
Deputy Team Leader – Hydrologist / Water resources expert	Postgraduate degree in Hydrology / Water Resources Engineering or other relevant field At least 10 years' experience in the field of hydrology / river engineering / water	9

Name of position	Qualification	Suggested man months
	resources engineering. Experience in morphology assessments will be preferred.	
GIS/RS specialist	Postgraduate degree in Geography / Geo-science or other relevant field with specialisation in RS/GIS. At least 5 years' experience in RS/GIS applications for resources mapping, preparation and integration of GIS data set.	6
Morphology modeller	Graduate degree in Civil / Environmental Engineering or other relevant field At least five years' experience in hydrologic and hydraulic modelling, in regard to morphological studies.	3

Note: The consultants are free to propose their own team composition suitable for the project over the twelve months duration of the consultancy.

5. <u>Payment and Schedule:</u>

- 10% mobilization advance against submission of Bank Guarantee (BG). BG shall be released after approval of the Report on Morphological trends & Priority Vulnerable Reaches and Training Plan
- 10% payment after acceptance and approval of Inception Report
- 20% payment after acceptance and approval of Report on Physiography and fluvial geomorphic categorisation
- 20% payment after acceptance and approval of Report on Morphological trends and priority vulnerable reaches and Training Plan
- 20% payment after acceptance and approval of Report on River morphology implications for flood management
- 20% payment after acceptance and approval of User Manual, Training Report and Delivery of Model

<u>11. Review and reporting</u>

The activities described earlier shall be completed within a period of twelve months. Key reporting requirements are as follows:

Report	Covering	Submission deadline
Inception report	Outlines the project scope, methodology, schedule, outputs and training plan	By end of second month from commencement of the services
Interim progress reports	Update on project progress	Within seven days after the

Report	Covering	Submission deadline
		end of each month
Report on Physiography and fluvial geomorphic categorisation	Report and associated GIS layers which classify the catchment physiography and fluvial geomorphic categorisation of the Rapti River in India.	By end of fourth month from commencement of the services
Report on Morphological Trends, Priority Vulnerable Reaches and Training Plan	Report and associated GIS layers which describes the broad scale morphological trends and processes of the Rapti River and identifies priority vulnerable sites where flood management assets are at threat from river processes.	By end of eight month from commencement of the services
Report on River morphology implications for flood management	Report and associated GIS layers which describes the morphological modelling results, river morphology processes occurring at each priority reach and the implications for flood management planning and infrastructure.	By end of twelve month from commencement of the services
User Manual, and Training Report and Delivery of Model		By end of twelve month from commencement of the services

Note: The reports will be reviewed and accepted by a Standing Review Committee (SRC) constituted by Irrigation & Water Resources Department, Government of Uttar Pradesh, within 30 days after submission by the consultant.

12. Period of Work:

12 months from commencement of the services

13. Procurement Method:

Quality and Cost Based Selection (QCBS)