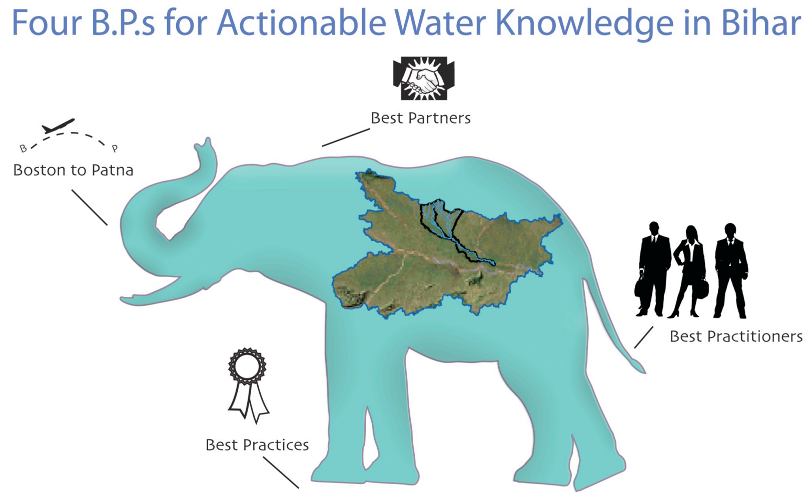
Water Management and Flood Forecasting:

A Synthesis of Global and Local information to Create Actionable Knowledge

An Example of Capacity Building in Bihar, India



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Bihar Flood Management Implementation Support Project

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Executive Summary

This report summarizes a component of the Government of Bihar's Flood Management Implementation Support Project Phase II with a focus on improving flood forecasting and management in the State. This follows and builds on the previous phase in which the World Bank supported Bihar in initiating a Flood Management Information System (FMIS) Cell, aimed to generate and disseminate timely and customized information to improved disaster preparedness and to effectively support flood control and management in the flood-prone areas of the State.

A key objective of this consultancy is to develop the technical and institutional capacity of the FMIS Cell on flood information and analysis. This was accomplished by two hands-on training sessions for improved flood management in the Bagmati-Adhwara (BA) basin. Two training sessions (December 06-10, 2010 and April 24-28, 2011) provided an overview of tools and techniques for flood forecasting and modeling. Three tasks were accomplished during these two on-site training at Patna as well as through a series of long-distance follow-up activities: (a) reviewed the current forecasting practices at the FMISC describing the knowledge base and methods along with an assessment of those methods within the context of internationally accepted flood forecasting and modeling techniques and tools; (b) provided a series of hands-on training exercises at the FMISC premises in Patna including comparison of rainfall data from rain gages, satellite (TRMM) and IMD sources as well as development of statistical flood forecasting models using water level and discharge data; and (c) initiated development and calibration of a freely available distributed rainfall-runoff model called HEC-HMS.

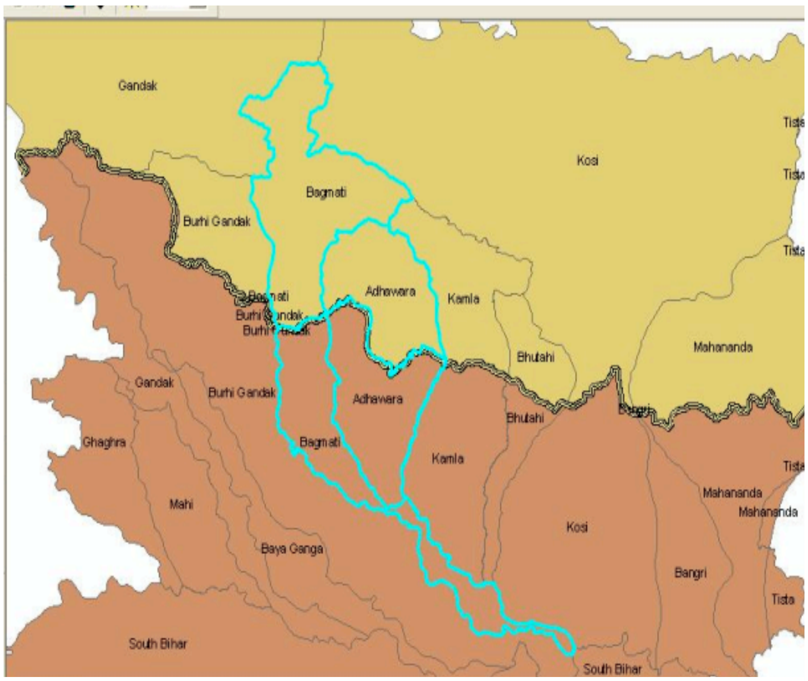
Based on these highly interactive training sessions and follow-up activities the FMISC water professionals developed a critical appreciation of inadequacies of "off the shelf" generic solutions of watershed modeling and forecasting without understanding the contextual reality of the watershed. This appreciation has led to an increased recognition that we must bridge the divide between "theory and practice" or between "know-why" and "know-how" with a new approach that can bridge this gap between theory and practice.

The proposed new approach is designed to bridge this gap by synthesizing global and local information with a focus on developing technical and institutional capacity at the local scale. We have illustrated this synthesis using Flood Forecasting at the Bagmati-Adhwara (BA) basin as an example with FMIS cell engineers and scientists from Bihar as active participants in the development and implementation of this new approach of capacity building with a four BP strategy: (Boston to Patna, Best Practices, Best Partners, and Best Practitioners) using BA basin as an example and Bihar Practitioners as the trainees.

Based on a series of interactive training sessions and follow-up activities with the FMISC water professionals we have concluded that: (a) a synthesis of best practices in flood forecasting models with contextual knowledge is essential to achieve high level of reliability and robustness for flood forecasting for the BA basin; (b) at the present stage, TRMM rainfall data or IMD forecasted data, at the daily time scale, may not be very effective to provide a forecasting lead time beyond one to three days; and (c) Rainfall-runoff models, such as HEC-HMS, may be customized with contextual knowledge from the BA basin to develop, calibrate, and validate an operational flood forecasting system. Such a model will allow FMISC professionals to actively engage in the development and implementation of an operational flood forecasting tool – with a goal to increase the forecasting lead time to 3-7 days - by synthesizing globally accepted best practices of flood forecasting methodologies with contextually relevant local information. This framework will also provide a mechanism to continuously develop technical capacity of FMISC water professionals through an in-house and customized BA flood forecasting model that can be continuously refined as more reliable data become available. This approach is consistent with the white paper prepared by CWC where they have highlighted the role of HEC-HMS type modeling for flood forecasting.

1. Context and Background

Bihar is India's most flood-prone State, with 76 per cent of the population in the north living under the recurring threat of flood devastation. Recurrent floods are devastating to Bihar's economy and undermine poverty alleviation efforts. Being flood prone not only affects existing investments, but also is a disincentive for additional investments in Bihar. There is a need to develop a long-term flood management strategy for Bihar based on analysis and stakeholder inputs that builds upon the wisdom of the substantial documentation that currently exists on the problem.



Forecasting Area -- Bagmati-Adhwara Basin

Traditional efforts at flood management have focused on *hardware* systems, such as the building of a system of embankments, many of which are poorly constructed and maintained. Despite the largely structural solutions that have been the focus of flood management in the past decades, the threat of floods remains as high as ever to the economy and livelihoods in Bihar. There has been excellent Government of Bihar documents (e.g. the 1994 Second Bihar Irrigation Commission, 2008 Sanyal Commission Report) that point to the need for a mix of structural and non-structural measures. They also emphasize that flood management needs to "form part of the overall comprehensive plan for optimum development of water resources of a basin." The Government of Bihar is keen on the speedy implementation of **Flood Management Implementation Support Project Phase II**, which would improve flood management in the State. This follows and builds on the previous phase in which the Bank, under a previous DFID-financed grant, supported Bihar in initiating a Flood Management Information System (FMIS) Cell, aimed to generate and disseminate timely and customized information to move the sector agencies from disaster response to improved disaster preparedness and to effectively support flood control and management in the flood-prone areas of the State. A variety of materials related to the status of floods in Bihar were produced using remote sensing and geographic information systems (GIS) techniques. There is an opportunity with Phase II to build on this to improve GoB capability to use state-of-the-art forecasts and to enhance last-mile connectivity for flood preparedness and information management through technical and institutional capacity building at the FMIS Cell.

2. Capacity Building in Water Management and Flood Forecasting: A Framework

Hydrological and climatic processes usually cover a wide range of spatial (watershed to continental) and temporal (minutes to decadal) scales. Here, we make a distinction between two scales: **Macro** and **Micro**. **Macro scale** refers to large spatial scales (regional to national) and longer time scales (seasonal to annual to longer time scales) while by **micro scale** we mean smaller spatial scale (watershed scale) and shorter time scale (several hours to days). Within this context, macro scale deals with issues of water resources planning and management while micro scale is more relevant for flood forecasting and disaster management.

Scientists and engineers have studied water problems and developed theories, tools, and techniques. While our effort to theorize about water systems has been vast; the set of tools and techniques available to pursue and implement these theories in practice has often led to science that is "smart but not wise". This is because we currently do not have the calculus to integrate our "scientific learning" with "the complex contextual reality" of real world water problems that are replicable and predictable. Yet, solutions to most real world water problems demands such integration. Consequently, the water professionals and managers who attempt to solve water problems cannot easily translated these solutions born out of **scientific findings** into the **messy context** of the real world of their watershed. The solutions to these real world water problems lie somewhere within these realms of knowledge; and effective solutions require bridging the divide between theory and practice.

The inadequacies of "off the shelf" generic solutions of watershed modeling and forecasting without understanding the contextual reality of the watershed has led to an increased recognition that we must bridge the divide between "theory and practice" or between "know-why" and "know-how." This realization often is conveyed in terms of "messiness" or "wicked" nature of water problems that arise when global "best practices" are implemented "locally" without understanding the uncertainty, ambiguity, nonlinearity, and intricacies of the watershed. We need a new approach to bridge this gap between theory and practice.

3. A Synthesis of Global and Local information to Create Actionable Knowledge

The proposed new approach is designed to bridge this gap by synthesizing global and local information with a focus on developing technical and institutional capacity at the local scale. Here, we will illustrate this synthesis using Flood Forecasting at the Bagmati-Adhwara (BA) basin as an example with FMIS cell engineers and scientists from Bihar as active participants in the development and implementation of this new approach of capacity building with a four BP strategy: (Boston to Patna, Best Practices, Best Partners, and Best Practitioners) using BA basin as an example and Bihar Practitioners as the trainees.

To date, two week-long hands-on training sessions (December 2010 and April 2011) were conducted in Patna along with a series of follow-up long-distance learning activities to ensure continuity between training sessions and reinforce the learning by doing.

4. An Adaptive Sequence of Hands-on and Follow-up Activities

4.1 Hands-on Training Session 1

Two key objectives of this phase (October 2010 – December 2010) were to: (1) review the current forecasting practices at the FMISC describing the knowledge base and methods along with an assessment of those methods; and (2) provide a series of hands-on training exercises on flood forecasting and inundation modeling at the FMISC premises in Patna.

The introductory hands-on training session (December 6 -11, 2010) was designed to review and assess current skill sets of the trainees within the context of flood forecasting and water management. This review was used to develop appropriate instructional material for the training as well as for follow up activities.

Preparation for the introductory training session focused on three key activities: (a) a thorough review of available best practices related to flood forecasting that included over forty refereed publications and reports; (b) review of available data sources for flood forecasting and water management; and (c) review of several existing rainfall runoff models including HEC-HMS. The training session focused on four B.P.s (Boston to Patna, Best Practices, Best Partners, and Best Practitioners) with a focus on the Bagmati-Adhwara (BA) basin. A brief description of the five-day hands on training session is given below with detailed session by session power point presentation and related material provided in Appendix I.

First inaugural session focused on providing the context, challenges, and opportunities to develop flood forecasting models and intellectual capacity at FMISC. Key issues presented and discussed are:

- A distinction needs to be made between flood forecasting (short time scale; less than a day to several days) and water resources management (longer time scale: seasonal to annual to decadal);
- Ideas of B.P introduced within the context of flood forecasting: (a**) Boston to Patna** – hydrology and climatology are dramatically different; Boston has a fairly homogeneous

rainfall distribution as a function of months while it is highly seasonal in Patna; [Slide 7]. Over 75% of Bihar is flood prone; recurrent and extreme floods affect Bihar. Yet, Bihar has significant potential to enhance its agricultural productivity through careful planning and management of its water resources. [Slide 8-10]; (b) **Best Practices** – current status of best practices in flood forecasting are discussed with examples from around the world. They include a synthesis of at least three different types of models: numerical weather prediction model; rainfall-runoff model; and flood innundation models with recent advances in data collection from satellites, radar and other sources. These models and data sources are synthesized to develop a range a flood forecasting tools. Accuracy of these flood forecasting models are primarily dependent on the accuracy and corresponding lead time related to rainfall forecasting and local hydrological conditions; (c) **Best Partners** – to develop an effective flood forecasting and water management team in Bihar, it is critical to develop long term partnership with a range of organizations with complementary expertise; and (d) **Be adaptive to Patna** – development and implementation of flood forecasting tools and related human capacity building need to be viewed and understood as a long term commitment with short term tangible and measurable outcomes.

- Primary water related challenges and opportunities for the Government of Bihar were discussed within the context of information, institutions, and infrastructures. It is argued that with long term commitment and effective organizational partnership with complementary expertise and resources, it is possible to develop **Best Practitioners** at FMISC who will be able to effectively integrate best practices from around the world with contextual knowledge from Bihar to develop flood forecasting models that will be superior to any existing models.

4.2 Follow up Activities: December 2010 – March 2011

Follow up Activity: FA1

Due: December 24, 2010

Our goal for this activity is to compare daily rainfall data from two rain gages in Nepal (Kathmandu and Nagarcoat) with the TRMM observed rainfall for six pixels covering the Nepal portion of the Bagmati-Adhwara basin (approximately 8000 km^2).

We provided water professionals at FMISC with detailed instructions on how to do the exercise. Box 1 shows the details of the activity FA1.

Box 1: Activity FA1

1) Identify the Adwara-Bagmati basin area in Nepal and find out which pixels you need to download for TRMM daily rainfall data from 1998-2010 (compare these pixels with the TRMM rainfall data provide in TRMM Data_Nepal.xls). Create an "average" time series of all pixels and call this TRMM_Rain
2) Create an average of two raingages from Nepal and call this GAGE_Rain

Our goal is to compare TRMM_Rain and Gage_Rain for the Monsoon Season (June – October). To do this, we will use the following procedure:

a) Plot the daily time series. Discuss the general characteristics of these signals. Plot an average monthly signal.
b) Estimate sample mean, sample variance, and sample autocorrelation function (up to lag 36). Discuss the nature of the autocorrelation function.
c) Find the correlation between the TRMM_Rain and Gage_Rain at the DAILY, WEEKLY, and MONTHLY scale.

Feel free to make assumptions (clearly write down your assumptions) and perform additional analysis keeping our goal in focus. Have fun exploring, and again, remember it is not the answer but the approach (a defensible one of course!) to arrive at an answer is important. Each trainee will summarize his/her experience with the assignment and send at least one question to clarify his/her understanding of the assignment. Send a summary of your findings (less than 5-pages write up) and all relevant Figures clearly marked with explicit legends and units by December 24, 2010.

This exercise demonstrated that the TRMM estimates did not show high correlation (r^2=0.28) with observed rainfall from rain gages on daily time scales. TRMM data did not capture the peaks of monsoonal rainfall. This activity was designed to (a) allow FMISC water professionals learn about the availability and processing of remotely sensed rainfall data; and (b) compare and contrast two sources (rain gage and TRMM) of rainfall data. A more detailed rainfall analysis was conducted in activity FA2.

Follow up Activity: FA2

Due: January 12, 2011

Our goal for this activity is to follow up on our findings from Follow up Activity 1. Box 2 shows the details for this activity.

Box 2: Activity FA2

Our goal for this activity is to follow up on our findings from Follow Up Activity 1. Please review the attached document (Follow Up Activity 1 Comments 122910.doc). As you have correctly identified, with increased level of aggregation (weekly, monthly scale) coherence between rain gage and TRMM data gets better. However, for flood forecasting with several days of lead time, we need to explore the utility of TRMM data at the daily time scale. Please work on the following tasks to arrive at meaningful and defensible conclusions regarding the utility of TRMM rainfall data at DAILY scale.

1) Please send TRMM daily rainfall (averaged over the domain you have chosen; i.e. 85.125E to 85.875E ; 27.125N to 27.875N for the period 2001-2009 (June-October) data as well as average of two rain gage data. This will allow us to make sure that we are using the same dataset in Patna as well as in Boston!
2) Estimate three metrics we discussed during our training session (averaged over 2001-2009; June-October) to compare TRMM daily rainfall with rain gage data.
   Bias, Correlation between average TRMM daily rainfall and average of two rain gages,RMSE = Square Root
   Please make sure that these three metrics are estimated as an average for June through October for 2001-2009.
3) Repeat Step 2 for RAINY days only.
4) Any other analyses (for example, Table on the last page of your previous report) that will help you make a "defensible" case for the utility of TRMM rainfall data at the daily scale.
5) As we have discussed, it will be effective if each of you write a "paragraph" summarizing your comments and findings from this exercise and include one question that you want me to address.

Send a summary of your findings and all relevant Figures clearly marked with explicit legends and units by January 12, 2011.

The FMISC team has done a detailed analysis of precipitation on a daily time scale for the TRMM and two rain gages from Nepal. A comparison of TRMM and gage data for various combinations (both TRMM and gage recorded rainfall; only TRMM recorded rainfall, etc) at the daily scale shows very low correlation (less than 0.20) and high root mean square error (17 – 20 mm/day) while the average gage recorded rainfall ranges between 10 and 17 mm/day. A careful examination of TRMM and gage rainfall data suggests that the low correlation is not related to a few outliers but a mismatch of TRMM estimated and gage observed rainfall at the daily time scale.

Based on these analyses it appears that, on a DAILY time scale, TRMM data is not an appropriate surrogate for rain gages in Nepal. Consequently, TRMM data averaged over the chosen domain (85.125E to 85.875E ; 27.125N to 27.875N) on a DAILY time scale is not suitable to use in modeling exercise or development of forecasting models for 3-7 day prediction lead time. In parallel, we, at Tufts University have done some analyses. On a seasonal (Figure 1) and monthly (Figure 2) timescale, we observe very high correlation (r^2>0.80 in both cases), which is not surprising and is well cited in literature (such as Nair et al., 2009). These results tell us that our retrieval of TRMM data and comparison with gage data are done accurately. On daily time scale, however, TRMM data are not appropriate for flood forecasting.

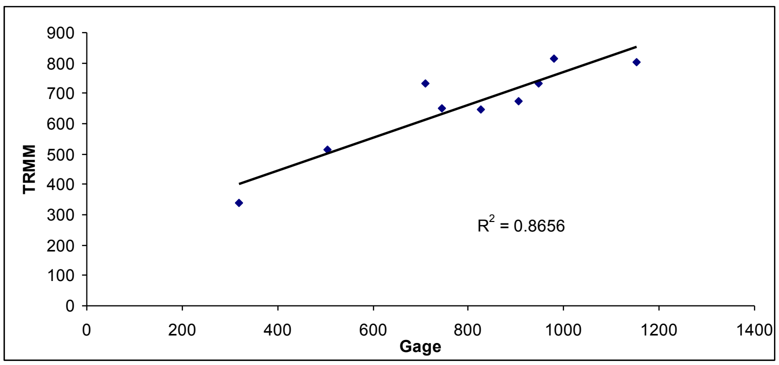


Figure 1: Total seasonal (JJASO) TRMM and combined gage rainfall (mm).

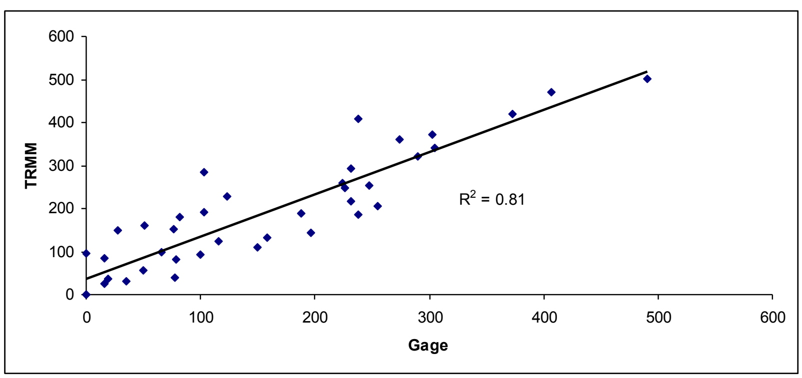


Figure 2: Total Monthly TRMM and combined gage rainfall (mm) (June through September).

Follow up Activity: FA3

Due: February 07, 2011

Given that TRMM data at the daily time scale is not suitable for flood forecasting purposes, we need to determine what is the next large scale database that can be used for flood forecasting purposes for the BA basin. Should we use rain gages or should we use gridded dataset? We know rain gages are very accurate for point measurements but with questionable spatial accuracy. From this perspective, use of gridded dataset will be more appropriate to calibrate and validate flood forecasting models. The goal of this activity was to determine what is the precipitation data source that we can use in to develop flood forecasting models?

Box 3: Activity FA3

IMD provides 3 day forecasted for precipitation at a 45km resolution. First, let us assess the "quality" of 3-day rainfall from IMD with rain gage observations over the BA basin. Let us begin….

(1) Compare IMD daily rainfall data (estimated not forecasted) over the entire BA basin (possibly all data points) with rain gages in Nepal (find if there is any lead-lag relationship) If there is a lead, lag relationship, then we can possibly use IMD dataset.

(2) Compare IMD daily rainfall data (estimated not forecasted; spatial region similar to Step 1) with rain gages in Bihar.

(3) Compare the IMD 3 day forecasts with actual observed rainfall in the region (both in BA basin as well as in Nepal).

Rainfall-runoff models are calibrated and validated using discharge data. Given that the availability of discharge data is limited and restricted, what is the best way to use it or make it available?

4.3 Hands-on Training Session 2

This session (April 24-28, 2011) focused on two objectives: (a) Provide a more comprehensive coverage of state of the art flood forecasting models, tools, and data sets and (b) Develop, calibrate, and validate a flood forecasting model on a storm scale for the BA basin. A brief description of the five-day hands on training session is given below with detailed session by session power point presentation and related material provided in Appendix II.

The opening meeting of the second training session was focused on providing the context, challenges, and opportunities to develop flood forecasting models and intellectual capacity at

FMISC. The Minister of Water Resources and the Principal Secretary of the Government of Bihar attended the session and provided feedback on how best to create actionable knowledge in Bihar.

15 Questions for trainees (review and warm up session); Summary of December Training; Plans for this training Session; Lessons learned from "long distance" exercises (e.g., TRMM rainfall analysis). Summary of responses for Questions: 1, 2, 14, and 15 is provided below. Responses to all questions are provided in Appendix II.

1. Please write THREE sentences describing what you have LERANED and REMEMBERED from our December training session and subsequent follow up activities.

- Eye opener regarding techniques and tools for flood forecasting.
- Exposed to different types of watershed modeling from development of models to calibration to validation as well as the idea of "zero order" model.
- Local knowledge is key to success in developing effective flood forecasting models
- Installation and preliminary implementation of HEC-HMS
- Downloading and processing of TRMM data
- TRMM data has a very low correlation at the daily scale for Nepal; correlation significantly increases for monthly data.
- Accuracy of forecasted rainfall is a pre-requisite to improve accuracy of flood forecasting
- Team effort is critical to develop an effective flood forecasting infrastructure
- Local knowledge must be integrated with global expertise
- Got an exposure to the idea of "actionable knowledge" and new approaches to address flood forecasting and water management problems.
- Follow up activities were very helpful to keep the learning effective and actionable.

2. Please write THREE concepts/ideas/tools that were not clear from our December training session that I must emphasize and clarify this time.

- Difference between lumped and distributed models; deterministic and stochastic models
- Availability of global scale data sets for flood forecasting and water management
- Expanded discussion about different types of models and parameters for HEC-HMS (e.g., loss method; transform method; routing method; etc.)
- Usefulness of TRMM data for the BA basin.
- Which model is appropriate for BA basin?
- Advantages and disadvantages of using TRMM rainfall data as well as IMD forecasted rainfall data for flood forecasting at the BA basin.

- How to get “real time” rainfall data from Nepal?
- How to “validate” IMD forecasted rainfall products?
- Even if we have adequate technical capabilities, lack of data will create problems for effective flood forecasting.

14. Assuming you have “adequate” resources, how will you design your “ideal” flood forecasting system for the BA basin with a forecasting lead time of 3-7 days? Please identify two most important variables (and justify your choice of these two variables) needed for this forecasting system.

- Rainfall and basin characteristic
- Forecasted rainfall and lag discharge
- 3-7 days forecasted rainfall; a rainfall-runoff model
- Validated forecasted rainfall; detailed catchment characteristics;
- Real time data analysis for rainfall; DEM, land use, land cover map
- Threatened embankment; sediment load

15. What THREE concepts/ideas/tools you want to learn during this training session?

- Depending on the data availability for the BA basin, what type of models/tools is appropriate for flood forecasting for the BA basin?
- How to run HEC-HMS for the BA basin?
- Develop an adequate HEC-HMS model for the BA basin
- How to increase forecasting lead time for the BA basin?
- Criteria to accept forecasted products for practical applications.
- What is a realistic and achievable forecasting lead time for the BA basin?

Based on responses and feedback, this training session was revised with the following sequence of learning activities: (a) Review session; rainfall runoff modeling; flood forecasting; (b) Gage to Gage correlation discussion; Hands on exercise to compare IMD forecasted rainfall with observed rainfall; (c) Compare IMD forecasted rainfall with observed data; Gage to Gage correlation among Kamtul, Benibad and Hayaghat. Start HEC-HMS for the BA Basin; (d) Continue hands on exercise and implementation of HEC-HMS for the BA Basin. Initial set up and site specific model parameters; (e) Calibration of HEC-HMS; explore sensitivity of different model parameters and components of HEC-HMS; (f) HEC-HMS for BA basin: Validation and THREE models with THREE groups; and (g) Review of two training sessions and lessons learned; discussion about RFP; Plans for the Future and "long distance" learning activities. A detailed description of these activities are provided in Appendix II.

4.4 Follow up Activities: April 2011 – June 2011

Follow up Activity: FA4

Due: May 24, 2011

Upon the completion of hands on training session II, FMISC professionals were given activity (Box 4) to develop statistical flood forecasting models with 24, 48, and 72 hour lead time.

Box 4: Activity FA4

You have water level data from Benibad, Kamtaul and Hayaghat. One day and two day lag correlation for water levels at individual stations is very high (>~0.95). Now let us start putting together the information within the context of the BA basin and build a set of statistical flood forecasting models.

First, let us develop a simple gage to gage correlation model for various time lags. Using data from year 2002, construct a series of models for forecasting water levels at Hayaghat at various lag time (1, 2, 3, 4, 5 days) using Benibad and Kamtaul data. Feel free to use any combination of stations. You can use any easily available statistical package (e.g., excel) to develop a set of regression model(s) and compute the fitted correlation value. Our objective is to (a) establish which of the stations (Benibad or Kamtaul) and what level is contributing to determine water levels observed at Hayaghat; and (b) develop a simple regression based statistical model for forecasting water levels at Hayaghat based on water levels from upstream stations.

Think about the following questions:

(1) What is the variability in water level data for these three stations? Compare variability with measurement error, if known?
(2) How variability in water level data is translated to observed discharge data?
(3) Why variability is high/low in water level data compared to discharge data?
(4) What is the travel time from Benibad to Hayaghat and from Kamtaul to Hayaghat?

What did you learn?

(1) Which station is contributing and by how much to flow/water levels at Hayaghat?
(2) What is the best lag time model (1, 2, 3, day etc) you obtain and which of the stations you found most useful to build your forecasting model?

Repeat the same exercise of building forecasting models with discharge data. Compare and contrast models with water level with discharge data.

Table 1 shows a set of statistical models for forecasting stage at Hayaghat. Various time-lag combinations using upstream gages were used to develop these models. The best model (correlation between observed and predicted stage is 0.977 in row 5 in Table 1) obtained using lag one stage data for Hayaghat, Benibad and Kamtaul gages.

Table 1: Statistical model for stage level forecasting at Hayaghat.

SN	Combination of input data	coefficient of determination 'r'	Regresion Equation
1	f(hayaghatlag1)	0.97	Y = 0.982 X + .782
2	f(hayaghatlag1,benibadlag1)	0.973	Y=.925 haya +.166 beni - 4.82
3	f(hayaghatlag1,kamtaullag1)	0.975	Y=.901 haya +.161 kam - 3.52
4	f(benibadlag1, kamtaullag1)	0.766	Y= .974 beni + .812 kam -43.34
5	f(hayaghatlag1,benibadlag1, kamtaullag1)	***0.977***	***Y=.857 haya +.145 beni + .150 kam - 8.132***
6	f(benibadlag1, kamtaullag2)	0.785	Y= .939 beni + .855 kam -43.735
7	f(hayaghatlag1,benibadlag1, kamtaullag2)	0.975	Y=.865 haya +.161 beni + .119 kam - 7.718
8	f(benibadlag2, kamtaullag2)	0.788	Y= .953 beni + .843 kam -43.779
9	f(hayaghatlag2,benibadlag2, kamtaullag2)	***0.939***	***Y=.724 haya +.254 beni + .284 kam -14.07***
10	f(benibadlag3, kamtaullag3)	0.78	Y= .916 beni + .854 kam -42.546
11	f(hayaghatlag3,benibadlag3, kamtaullag3)	***0.889***	***Y=.613 haya +.324 beni + .38 kam - 17.371***

Aggregated statistics, provided in Table 1, may not reveal intricacies associated with adequacy of flood forecasting. To demonstrate the inadequacies of correlation coefficient as a metric to evaluate adequacies of flood forecasting, we used daily discharge data of Hayaghat from June 15, 1995 through October 15, 2005 (four months for each year) to construct simple linear regression models for five day lead time. Out of total time period of 11 years, two years (1999 and 2000) of data were separated for validation of the model. Table 2 shows the performance statistics for these regression models. Prediction r^2 (accuracy of the developed model to fit the observed data) and validation r^2 are very high**.** In addition, bias and root mean square error (RMSE) values are satisfactory given the average river discharge from June 15 to October 15 in the two validation year is about 709m^3/s. However, Figure 3 and Figure 4, clearly shows that there is a significant shift while estimating of peak discharge, meaning that the persistence based statistical models will not work efficiently.

Table 2: Discharge Forecasting Model performance statistics for Hayagahat

Lead Time	Prediction R^2	Validation R^2	Bias (m^3/s)	RMSE (m^3/s)
Day 1	0.98	0.97	1.78	54.92
Day 2	0.94	0.92	4.43	92.36
Day 3	0.89	0.88	8.21	127.12
Day 4	0.83	0.81	15.35	162.32
Day 5	0.78	0.74	18.28	180.45

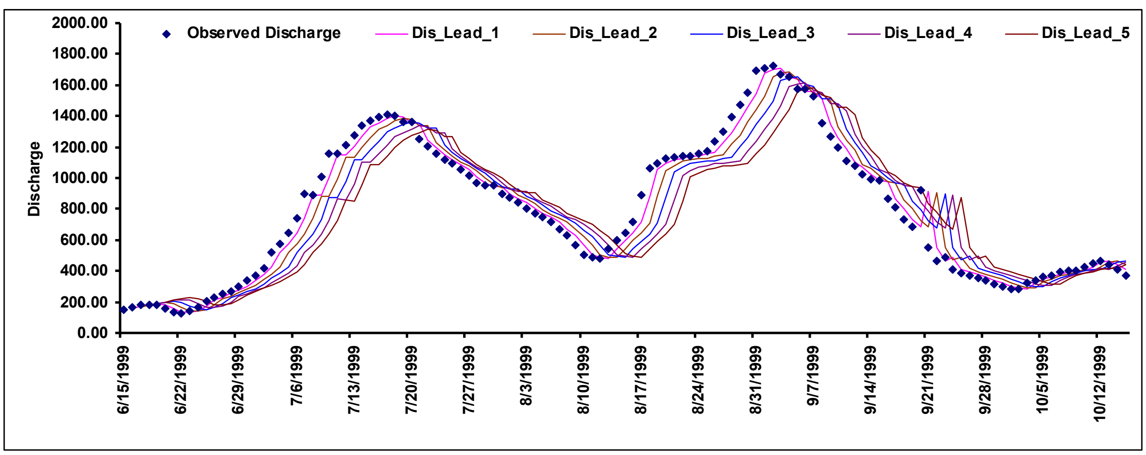


Figure 3: Observed and predicted river discharge (year 1999) at various lead times for Hayaghat

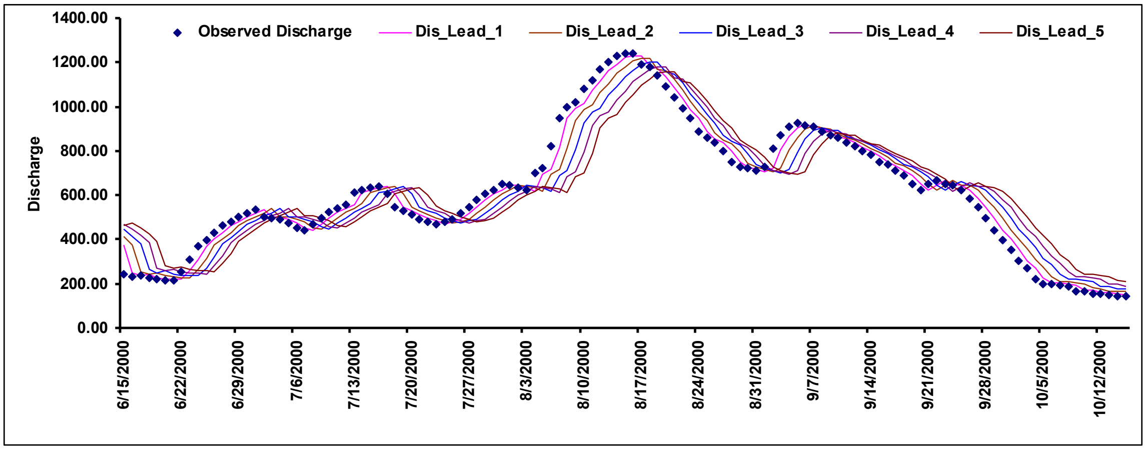


Figure 4: Observed and predicted river discharge (year 2000) at various lead times for Hayaghat

5. Summary of Two Training Sessions, Follow up Activities and Future Plans

From two training sessions and four follow up activities, BP (Best Practitioners) partners from Patna FMISC have developed

- a good understanding of state of the art rainfall runoff modeling and flood forecasting;
- the skills to calibrate and validate a rainfall runoff model for flood forecasting;
- the capabilities to use TRMM, IMDB and other rainfall data set for daily forecasting
- the skills to evaluate capabilities and deliverables from the "flood forecasting model" vendor/company FMISC will hire for the next step of the project.

Future plans (June 2012 – December 2012) will focus on two activities: (a) continue follow up activities with three groups to develop a more in-depth understanding of using TRMM and IMD data for calibration and validation of HEC-HMS customized for the BA basin; (b) provide third hands-on training session (Dates to be decided) to further enhance BP partners skills to analyze available data and HEC-HMS model for flood forecasting and determine the limits of forecasting lead time for the BA basin.

Appendix I

Hands-on Training Session 1

Two key objectives of this phase (October 2010 – December 2010) were to: (1) review the current forecasting practices at the FMISC describing the knowledge base and methods along with an assessment of those methods; and (2) provide a series of hands-on training exercises on flood forecasting and inundation modeling at the FMISC premises in Patna. A brief description of the five-day hands on training session is given below with detailed session by session power point presentation and related material provided in Appendix I.

Following files are included in Appendix I

Questionnaire December 2010.pdf

This is a "warm-up" session. This is a "base level" information gathering exercise; please be candid and provide answers as best as you can and feel free to ask related questions in your response to these questions. Only wrong questions are the one you do not ask; so, please ask questions and let us make this an interactive conversation where we learn together to **CREATE ACTIONABLE KNOWLEDGE** for Bihar. This is the only way to resolve water issues in Bihar: By creating **BRILLIANT PRACTITIONER** who are from Bihar with technical "know how" as well as "contextual wisdom".

T1D1AM.pdf

First inaugural session on December 06 morning focused on providing the context, challenges, and opportunities to develop flood forecasting models and intellectual capacity at FMISC.

T1D1PM.pdf

A questionnaire was distributed (attached) to understand the current needs and available skill sets of the FMISC. Response from this questionnaire was used to adapt the instructional material for the rest of the training session. Trainees wanted to focus the instruction on the BA basin.

T1D2AM.pdf

This session focused on a range of watershed modeling options ranging from (i) deterministic to Stochastic Modeling; (ii) Simple, Complicated, and Complex systems modeling; and (iii) four types of simples models were discussed: Logistic Equation and Fourier Representation; Linear Regression and Normality.

T1D2PM.pdf
Remote sensing of watershed processes; basics or remote sensing, estimation of evapotranspirtion, soil moisture, and precipitation with remote sensing.

T1D3AM.pdf
An overview of HEC-HMS modeling framework was introduced. Availability of data for the BA basin and appropriate modeling strategies were discussed.

T1D3PM.pdf
This hands-on training session focused on downloading HEC-HMS model and implementing it on their computer. Trainees have worked on developing a HEC-HMS simulation using a hypothetical basin called "Castro" to get them familiar with various steps of modeling discussed on Tuesday. Different steps in model development, parameter estimation, calibration, validation, simulation, and forecasting were discussed.

T1D4AM.pdf
A hands-on exercise was designed to show the relationship between daily stream flow and rainfall to emphasize the issues of scale and heterogeneity in hydrologic processes. Given that limited rain gage data are available, step by steps procedure was shown on how to download and process rainfall data from TRMM (Tropical Rainfall Measuring Mission) Satellite.

T1D4PM.pdf
This hands-on session focused on implementing HEC-HMS for the BA basin with actual shape files and basin geometry. This initial set of HEC-HMS model will be used to customize the model with BA specific model attributes and data over the next several months.

T1D5AM.pdf
A detailed review of key concepts and watershed modeling were presented. A plan for the next several months session was discussed.

Follow up Activities
FA1.pdf
FA2.pdf
FA3.pdf

Training Feedback December 2010.pdf
December 2010 Training Report FMISC.pdf

Appendix II

Hands-on Training Session 2

This session (April 24-28, 2011) focused on two objectives: (a) Provide a more comprehensive coverage of state of the art flood forecasting models, tools, and data sets and (b) Develop, calibrate, and validate a flood forecasting model on storm scale for the BA basin. A brief description of the five-day hands on training session is given below with detailed session by session power point presentation and related material provided in Appendix II.

15 Questions BP 042411.pdf

This is a "warm-up and review" session. Please spend no more than 60 minutes to answer these questions. Please be candid and provide answers as best as you can and feel free to ask related questions in your response to these questions. Only wrong questions are the one you do not ask; so, please ask questions and let us make this an interactive conversation where we learn together to **CREATE ACTIONABLE KNOWLEDGE** for Bihar. This is the only way to resolve water issues in Bihar: By creating **BRILLIANT PRACTITIONER** who are from Bihar with technical "know how" as well as "contextual wisdom".

T2D1PM.pdf

The opening meeting of the second training session was focused on providing the context, challenges, and opportunities to develop flood forecasting models and intellectual capacity at FMISC. The Minister of Water Resources and the Principal Secretary of the Government of Bihar attended the session and provided feedback on how best to create actionable knowledge in Bihar.

T2D2AM.pdf

15 Questions for trainees (review and warm up session); Summary of December Training; Plans for this training Session; Lessons learned from "long distance" exercises (e.g., TRMM rainfall analysis.

T2D2PM.pdf

Review session; rainfall runoff modeling; flood forecasting.

T2D3AM.pdf

Gage to Gage correlation discussion; Hands on exercise to compare IMD forecasted rainfall with observed rainfall.

T2D3PM.pdf
Compare IMD forecasted rainfall with observed data; Gage to Gage correlation among Kamtul, Benibad and Hayaghat. Start HEC-HMS for the BA Basin;.

T2D4AM.pdf
Continue hands on exercise and implementation of HEC-HMS for the BA Basin. Initial set up and site specific model parameters

T2D4PM.pdf
Calibration of HEC-HMS; explore sensitivity of different model parameters and components of HEC-HMS.

T2D5AM.pdf
HEC-HMS for BA basin: Validation and THREE models with THREE groups

T2D5PM.pdf
Review of two training sessions and lessons learned; discussion about RFP; Plans for the Future and "long distance" learning activities

Follow up Activities

FA4.pdf
FA5.pdf

Training Feedback April 2011.pdf
April 2011 Training Report FMISC.pdf