Discussion Meeting On Scale Issues In Hydrology

December 01- 03, 2019

Hassan
India

Interdisciplinary Centre for Water Research
Indian Institute of Science, Bangalore - 560012

Authors: Neha Khandekar, ATREE
Gowri R,Civil Engg Dept., IISc
Kuashika G S, ICWAR, IISc

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December 1-3, 2019
Hoysala Village Resort, Hassan

न चोराहार्यम् न च राजहार्यम् न भ्रातृभाज्यं न च भारकारि।
व्यये कृते वर्धत एव नित्यं विद्याधनं सर्वधनप्रधानम्॥

Neither can it be stolen by thieves, nor can it be taken away by the kings. Neither can it be divided among brothers, nor does it have a weight. It keeps growing if spent (shared) regularly. The wealth of knowledge, is indeed the most superior wealth of all!

The new scientific decade 2013–2022 of IAHS, entitled "Panta Rhei – Everything Flows", is dedicated to research activities on change in hydrology and society. The purpose of Panta Rhei is to reach an improved interpretation of the processes governing the water cycle by focusing on their changing dynamics in connection with rapidly changing human systems (Montanari et al., 2013).

The workshop on "Scale Issues in Hydrology" was conceptualised by Professor M Sivapalan, University of Illinois (Satish Dhawan Chair) and Professor Mujumdar, ICWAR, IISc as a continuation of the conversations on catchment hydrology through a course offered by Professor M. Sivapalan. The discussions spread over the course of three days were held in the picturesque Hoysala Village Resort in the quaint town of Hassan, away from the hustle and bustle of Bengaluru city. The discussions were organised in the form of 4 sessions spread across three days including presentations from participants and brainstorming break-out sessions. The participants (list enclosed in Annexure) comprised of Assistants Professors from Indian Institute of Technology across the country, National Institute of Hydrology as well as senior Professors from ICWAR engaging with a variety of research topics in surface and groundwater hydrology as well as remote sensing, GIS.

<u>Attendees (Abbreviations)</u>
Murugesu Sivapalan (MS), Pradeep Mujumdar (PM), Mohan Kumar (MK), Balaji Narasimhan (BN), Nagesh Kumar (NK), Satish Regonda (SR), Argha Banerjee (AB), J Indu (JI), Sagar Chavan (SC), Seetha Narayan (SN), Karthikeyan Lanka (KL), Debsundar Dutta (DD), Rajarshi Bhowmik (RB), Neha Khandekar (NK), Lakshmikantha N (LN), Kaushika G S(KA), Gowri R (GR), Shailza Sharma (SS), Ila Chawla (IC), Pankaj Dey (PD), Walter Samuel (WS), Deepak Bisht (DB), Nithesh Patidar (NP), Susmita Raha (SR)

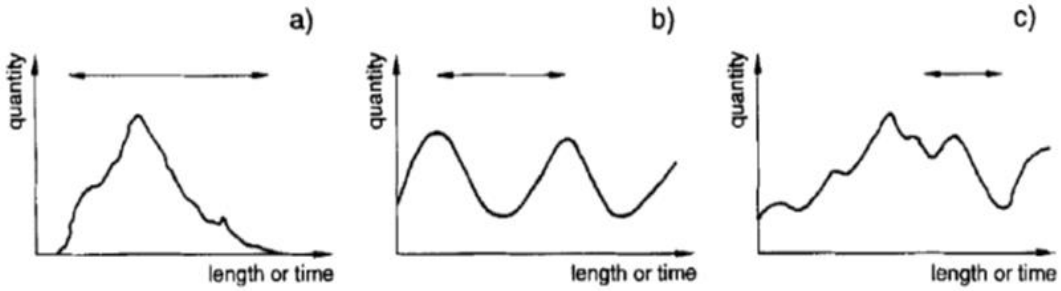
1. Introduction - Day1

Prof Mujumdar welcomed all the participants and discussed the need for the Discussion meeting and recalled the discussion with Prof Sivapalan. Prof Mujumdar said that the meeting is the brain child of that discussion and it intends to sow seeds to look forward to address the scale issues at a larger scale and with India leading the way this time. He also emphasized on the aptness of the location and the time as the scale issues in hydrology are relevant to address all the social and technical issues in hydrological studies. This was followed by all the participants introducing themselves and their research areas.

Professor Sivapalan made the first presentation to set the stage on scale issues in hydrology in the anthropocene.
There have been 4 international workshops across a span of late 80s and 90s in the history on the topic.

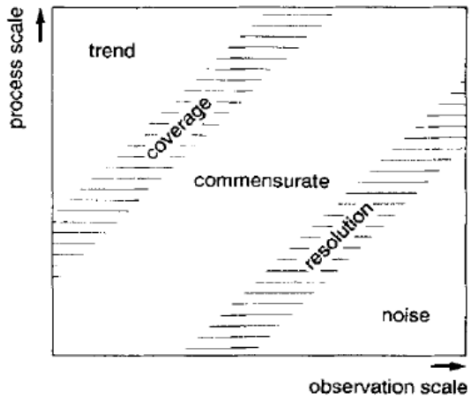
	Year	**Place**
1	1981	Caracus, Venezuela,
2	1984	Princeton, USA
3	1993	Canberra, Australia
4	1996	Vienna, Austria

Until 1996, scale issues were a dominant problem in hydrology. There is a hope that the present set of discussions can evolve into the next international conference led by the Indian hydrology community.



(Sivapalan, 2019)
It is curious how heterogeneity manifests itself. When one looks at a system using scale-lens, a very complex process of water partitioning in nature across different systems at

micro scale can be represented by a simple unit hydrograph at macro scale. That is, something very complex at small scales turns into something simple at large scale.
Scale is a very nebulous concept but what it essentially means is having a sense of proportion about anything - think of an analogy of an insect to a human.



There is space and time scale and then process scales in both space-time problem because measurement (observation) scale is different from process scale - leading into noise/ trend. So, applying Richards equation/hydraulic conductivity computations at 1 m scale to 10 km scale does not have a meaning. Neither does applying Index flood method based on assumption that CV is constant, which holds true only for small regions. One upscales or downscales the information to fill the gap. The problem lies in defining the parameters at both scales but also defining the process itself. We need effective parameters for capturing heterogeneity and its effects on our models in mimicking the real world. The key point here is that this heterogeneity is not random but organised in nature that is there is organised variability or nature is self-organised. In fact, the representative element area (REA) exists because of this organisation. One way to understand the scale problem is to ask an interesting question - a 'why' question or discovery question behind the process. Another way is to ask a question related to practical problem. One must look at a phenomena unfolding and ask 'Why?' There exists a relationship between space and time also. Just like space scales, time scales are also organised. For example, at long time scales, partitioning of water just becomes a competition between energy and water. Researchers must ask - why? In other words, on probing, catchment reveals itself to you. So, one can argue whether how complex should a model then be? Normally properties of the landscape govern hydrology - you have fast and slow processes governed by dynamics of vegetation. Additionally, there are human interventions and humans and landscape co-evolution in processes. Basically, everything changes and interact with each other creating in creating emergent dynamics in anthropocene. Thus, 'Social Budyko curve' is wherein trees and humans are mediating competition between energy, land and water.
So one of the fundamental questions is at what scale should we model? But in anthropocene, more interesting questions are in time domain in rapidly evolving watersheds. We need a diversity of ideas and framing problems in scales.

General Discussion - Rephrasing research works in terms of space-time scales

SN - deposition of colloids in few centimeters of soil is simpler to model but in the real world, deposition is happening at micrometer scale. What are the processes needed at smaller scale are how is the interplay at air-water-solid surface? These are pertinent questions.

LN - Anthropogenic changes are dominant in catchment hydrology at small scale in sub-basins and their impact needs to be understood at larger scale. It is found that anthropogenic impacts are more than climatic factors.

IC - Transferability of models across space scales and time scales and their use for prediction in ungauged basins is needed. We need a framework based on which we can transfer a model across scales.

AB - Whether the input parameters be modeled or downscaled? GCM products contribute to 35% of uncertainty. Dimension analysis for finding glacial volume is one way to tackle model challenges. Wants to use simple models with less number of parameters.

MK- The question is whether one should revisit the physics behind processes and scale it up or we should move forward with the presently available models.

There are scale issues in remote sensing as well.

DD – Hyper resolution datasets - Treating canopy as a spectral thing and modelling it is one way. Instead of lumping processes into parameters, preferring well distributed model framework.

JI - What is the optimum way to conduct measurement given timing/ frequency of satellite overpasses?

KL - There are point scale soil moisture measurements and upscaling/downscaling this at spatial scales is the challenge. How to take soil moisture representations at time scales with respect to satellite measurements.

DB- There are challenges in coarse scale to fine scale data downscaling, for example TRMM satellite data issues.

BN- Landholdings of farm lands are smaller than satellite data availability scale, and cloud cover is a problem so we don't get data continuously. Scale issues stares at our face as first thing in modelling, parameters may not be collected at the same scale. Are processes being integrated at same scale before modelling? Data is being collected but not necessarily at scale where we are looking at the problem. Processes are scale sensitive so how do we convert gridded data into real world scale?

NK- Two extra scales - spectral and radiometric resolutions are also there with respect to remote sensing products. In all four dimensions (spatial, temporal, spectral, radiometric) scale issues are dominant.

Concluding Note- MS- Why do things look simple at one scale but complex at a different scale? We should develop thinking in terms of time scale and space scale and wear both hats - of discovery and problem solving.

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2. Short Presentations & Breakout session – Day 2

2.1. Short presentations

Porous Media Complexity- by Prof. M. S. Mohan Kumar

- Darcy scale does not apply for porous media but we keep applying it at Darcy scale by lumping.
- Scale systems acts differently for fractured and alluvial aquifers and it is very complicated to understand the underlying phenomena.
- There are what we call direct methods and surrogate methods which are used when direct estimates are not available at scale of interest. It is curious to understand how recharge rate varies in space and time.
- Another interesting question to study is how do we move from pore scale to regional scale - how do we get that equivalent permeability?
- How do we learn at very small scale and upscale the process learning it at regional scale for improving our understanding?
- Upscaling issues for coastal aquifers.

Comments - MS - scale issues need to be understood not only in surface water but also in groundwater and also transport mechanisms in porous media as both surface and ground water are to be inter-connected.

Hydrologic modelling for effective management of land and water resources- by Prof. Balaji Narasimhan

- Some of the challenges that we face in this area are - NDVI is available at larger scale than plot scale in fields.
- Temporal profile of NDVI is disaggregated to study crop phenology and disaggregation of radiometric surface temperature is also derived.
- Because of cloud cover, we lose data spatially and temporally.
- Scale issues persist at all scales in remote sensing.

A few hydrology questions - By Dr. Satish Regonda

- What scale should we be looking at - decision scale/ science/ application and what are the interconnections across scales?
- For example, for a real time flood forecasting forecast in Godavari basin using HEC-HMS, should we study using event or continuous simulations? Lumped or semi-distributed?
- Do we use drone derived fine resolution data or satellite coarser data? How do we tackle the issues of satellite passes and frequency challenges?
- Urban flood modelling - is not able to be captured for finer scale (1 km stretch for example) so using drone derived data seems to be plausible but handling data at such a fine scale becomes a problem.

Comments – NK - At large scale (river basin), we don't have to go at fine spatial resolution. We should know at what finer scale we should stop modelling.
IC – The resolution of DEM data does not affect the overall results in modelling at a lumped or coarser scale.

Parameterization of slow glaciers in hydrologic modelling - by Dr. Argha Banerjee

- The study throws light on resolving scale issues from parameterization examples in glacial hydrology.
- Usually glacier is treated as land use /land cover due to static nature but in multi decadal scale, its storage changes.
- The processes are actually time dependent so need to incorporate a time component.
- Parameterization at time scales is done. Dimension analysis can be helpful.
- Power law relation between volume and area reveals problem with underestimation of glacial volume.
- Glacial behavior can be easily explained by a simple linear response theory.

Comments – MS - This shows how we can use simple models to explain complex phenomena; we come up with first order equations as explanation.

Sampling considerations for robust precipitation constellation- By Dr. J. Indu

- Transition of scales from orbital data to gridded data reveals challenges as to who decides how many satellites should capture the data in a constellation - for example 13 satellites in GPM constellation? What is optimum satellite number in constellation?

- In satellite based remote sensing of precipitation - accumulated rainfall over space and time at grid scale is estimated. For example, US classified data was used in the study available at 30hr at 0.01 degree having different sensors in microwave region.
- Investigation of sampling errors from different satellite data due to sparse space-time precipitation.

Importance of scaling properties in designing flood estimations - by Dr. Sagar Chavan

- Mono and multi scaling properties of annual peak flows and self-similarity properties. Power law between area and peak flow can be obtained.
- Scaling of statistical moments
- Bifurcation ratio can help in identifying which sub-basin is dominant.

Comments – BN – We should not choose arbitrary thresholds but optimal threshold for particular DEM resolution should be chosen.
PM - scale issues in extremes, urban areas - time variance of parameters, scale issues are dependent on land use patterns.
DB – for urban flood modelling 2.5m resolution is enough
SC - relation between moments and area not better (less than 0.6 R^2 values) - area is playing important role in peaks, peak is scaling with area, and power laws are different.
MS – surface- groundwater interactions should be extensively studied.
BN – scale issues in remote sensing is also dominant.

2.2 Breakout session

The participants were divided into 4 groups to discuss scale issues in hydrology based on-space, time, space-time, space-time-human mediation

Breakout Groups

Space Scales	Time Scales	Space-Time Scales	Scale Effects Due to Human Interventions
Mohan Kumar	J Indu	Nagesh Kumar	Balaji Narasimhan
Seetha Narayanan	Sagar Chavan	Ila Chawla	Satish Regonda
Nitesh Patidar	Debsunder Dutta	Argha Banerjee	Deepak Bisht
Walter Samuel	Pankaj Dey	Gowri R	Neha Khandekar
Shylza Sharma	Karthikeyan Lanka	Kaushika G S	Rajarshi Bhowmik
			Lakshmikantha

DISCUSSION OUTCOMES

Group1: Space scales

- Rainfall data has spatial scale issues. Data is available at point to various different scales from sources like rain-gauge, satellites, and sadar data which are at different scales. Error in rainfall measurements amplifies the errors in hydrological models.
- DEM, LULC, Soil & Rainfall are all available at different spatial resolutions. Hydrological models are at another scale. How do we integrate these scales in hydrological models? Can spatial extreme events be represented with point data? For groundwater- Darcy's Law is at cm scale, and is applied at larger scales. Is it actually applicable at larger scales?
- Due to heterogeneity, basic processes may change, when we move from one scale to another. So, what is the lowest scale of heterogeneity to be considered at catchment scale? Are these scales different for subsurface, surface & atmosphere? How is the land surface and subsurface scales link up? What is the dominant process to be looked at, at a particular scale? Depending on the problem we are addressing the processes need to be identified. Uplands, midlands, lowland, coastal processes are different. What about their scales?

Group2: Time scales

Process and scale of interest in India: Precipitation, runoff, vegetation, soil moisture - By – JI, SC, PD, DD, KL

- SC - Scale of interest can change from hourly (urban) to daily (natural). How we move from one scale to other is a challenge. There is dependence structure between scales. There also is branching of the time scales. Conservation of mass has to be retained while moving from one scale to other. We need what is called a Cascade model.
- PD - Time scales and space scales are interlinked. If we move from coarser to finer scale, complexity of the models increase. Larger timescales have more to do with water and energy budget than smaller time scales.
- DD - Challenging problems are response of vegetation to ET, seasonal variability of parameters like NDVI, and effective parameterization. We use SIF timescales at monthly scale in climate models. Can we use SIF along with other datasets to assess droughts? We strive to improve the dynamics of models.
- KL - Can we establish link between soil moisture at different timescales? What is preventing us to look at finer temporal scales?

About nature of heterogeneity/variability/organization and controls:

- SC - Precipitation at finer scale has several gaps and to fill the gap, one has to do averaging.
- JI – If IMD can provide sub-daily data it will be beneficial.
- DD - We have SIF data at daily level.
- PD - Inspite of catchment heterogeneity, catchment has memory and at large scale it does not matter. Memory is dependent on the process that drives it. Snowmelt, rainfall, or mixed, have different memory. But this memory is disturbed due to human impacts like urbanization.

Discussion on scale problem (upscaling and downscaling):

- KL - We need a framework to link persistence decay with time and extremes.
- PD - We need to incorporate memory feedbacks.
- DD - For Ground data at 15 min (spectrometers), upscaling (time averaging) is more meaningful.
- SC - Can aggregation be extrapolated? How reasonable is time invariance when the distribution of random variables is changing across scales, for disaggregation? What is the validity of assumption of equality of distribution? In the context of temporal disaggregation, what is the validity of assumption of equality of distribution?

Scale interaction and emergent dynamics:

- PD - What about scale properties of inter-year time scales?
- DD - Spectrum of time series can be linked with specific processes. Process level understanding is dependent on the time scale at which we look. Assumptions and processes are very important to assess the time series at various scales.

Addressing scale problem:

- SC - Do we need fine temporal resolution data for all datasets? It depends on application.
- Do we need to ponder on the memory of individual plants within cropping/growing days/day, sub-daily data?
- Temporal aggregation is not always averaging and is okay for larger scales.
- PD - What if we monitor fast and slow components of flow with data sharing?

New laws:

- PD - Complexity versus aridity of catchment. Simple indices such as aridity index can be used to talk about the catchment processes. Very few numbers that are dimensionless can explain physics.
- SC - Link between finer and coarser time scales. If we know how a parameters of a particular law are changing with time, can we establish the dependence between the parameters across the scales? Can we consider other variables while talking about temporal scales of one variable? Does increase in math complexity increase the uncertainties? Can we arrive at an optimum time window to have a process level understanding? Can we come up with broken power law across different time scales for a particular process?

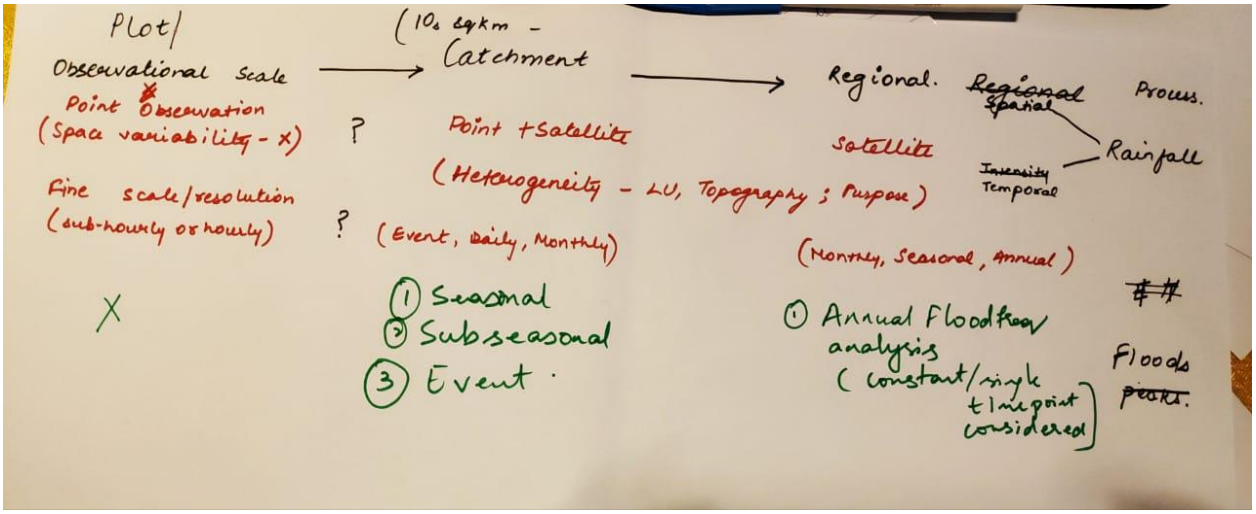
General Discussion:

- Rainfall data availability is at different scales. Integrating it in hydrologic model is challenging.
- Layers in model are at atmospheric level, surface water, vadose and groundwater zone - what is REV for these? How do we represent extreme from point data ? Our present scale of applicability is Darcy's law.
- Dominant processes need to be studied at a suitable scale. At catchment scale, what is the lowest level of heterogeneity that should be considered?
- Time scales - There is a need to establish linkages across scales in various processes and processes that are driving these variables.
- Can we develop a framework that works across time scales?
- Understanding the nature of heterogeneity,
- A knowledge of the memory/footprint of the process helps in understanding the fineness of the scale of study.
- Why not work with finer temporal resolution data, like sub-daily scale? Is it lack of observation data or not necessary?

<u>Group3: Space-time scales</u>
Group members – AB, KA, IC, GR

- While a plot scale is a few kms, a catchment scale may range from anything between 10 sq.kms to 1000 sq. kms and a regional scale may range from 1000 sq. km. to entire the country India. Choosing the scale of study is dependent on the problem and the process which we want to study. We should look at the heterogeneity in the region and then determine the scale.

- How to reconcile scales at which driver variables are available (in both time and space) and the scales we are trying to model processes?



<u>Group 4 : Space & time scales and nonstationary space-time pattern dynamics (coupled human-nature systems)</u>

- LN - Changes in cropping pattern are driven by socio-economic factors and that in turn affects the bio-physical processes (ET, rainfall).
- At regional scale, model becomes easier to understand, co-evolution is captured, but how to do we upscale from plot level (representative plots - milli catchment) to regional scale?
- RB - Thinking in terms of scales from micro-pores to geology (biometeorology), heterogeneity to management scale (scale at which water is managed). How large spatial variability at atmospheric scale is getting translated to watershed scale where periodicity at lesser time scale frequency? And what are the inputs in this case? In terms of modelling unit - at what scale are you looking at the management processes?
- What is it that we are observing and what is it that we trying to model? Observation scale versus process scale - in this framework where does human intervention come into play? There may be multiple clusters of human dimensions - need to connect space -time scales and connect to human interventions. Land use changes becomes most critical from hydrology perspective. Where does LULC changes affect scale - soil moisture, ground and surface water? In a conversion of say Forest to agriculture, there is significant impact on the springshed.

- Even within forest land cover, pine versus mixed forest impacts the spring discharge and there has been increase in pine forests due to human intervention. Other examples are of rise in groundwater pumping, reservoirs on rivers, and cascading tanks, each having an impact on parameters - rainfall and in turn streamflow - (overland, interflow, baseflow), soil moisture, ET. Again the scale of observation of process matters. Total streamflow observation changes depending on where you are in catchment. Urban flooding for example - more of the interest goes in studying at larger time scale.
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- The Curve Number method that we commonly use for capturing LULC change - is there a scale issue involved? How do I capture this change in parameterization?

<u>Discussion</u>

- Through what lens we are looking at process should determine the scale. How do we go from observation scale to catchment scale? For determining our region/ catchment scale - we need to pick up our appropriate space and time scale. Flood peaks become relevant at catchment scale. At regional scale, one can compare and only look at annual flood peak.
- MS - Scale is a topic that brings people together. One can study by assuming space in a steady state to study other processes evolving in time and vice versa. Some of the variability gets phased out in space as process propagates through the system.. Human feedback have significant impact at all scales in anthropocene and cannot be overlooked.

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3. Short presentations and breakout session – Day3

3.1.1. Short presentations

Scale issues in hydrology- a Remote Sensing perspective - by Prof. D Nagesh Kumar

- Scale issues in this area are multi-dimensional - Spatial, temporal, radiometric and spectral resolutions.
- Hyperspectral sensing is employed for computing hydrologic fluxes. Detailed information is available at finer scale for example for high radiometric resolution for drought monitoring.
- Hyper-spectral sensing helps in distinguishing different soil types using characteristics like mineral content and organic matter; different growth stages of crop; ET etc.
- While technology has advanced, the challenge is still of dealing with large data and what figuring out appropriate scale for solving problem. Also developing a model which is transferable/calibrated to multisite and multi variables.
- Comment – MS - Spectral scale seems like integration of space and time.

Colloid transport in porous media- pore to field scale - by Prof. Seetha N.

- The challenge in modelling this is often the grain size is smaller than Representative Elementary Volume (REV) and Darcy scale, where averaging theory works cannot be used at field scale, which is highly heterogeneous.
- Colloidal transport occurs at interface between solid and liquid interface or between pores. The challenge is to understand how larger scale processes are associated with a representative scale.
- For column scale, most common scale where transport mechanisms are at solid or air-water interfaces.
- In a study conducted, when we compared breakthrough curves from experiment and upscaling, we found that there is a gap between model and experiment. We are still trying to discover whether that is because of scale issues or heterogeneity?

Comments – MS - Hydrology is waiting for answers. So we have to get short cuts to get to larger scale (catchment) and attempt at answering important questions. For example - what is the effect of macro pores? Does Darcy law work at that scale? Some real world challenging problems are waiting in hydrology which happen at much larger scale. What we need to ask is - can we find short cuts / breakthroughs in studying sub-surface particle dynamics for contributing to estimations in field of surface and groundwater hydrology.
Catchment and ground water hydrologists deal with 100s of kms, so Groundwater hydrology has to evolve from porous media scale to large scale. Dual porosity model is just a Band-Aid solution. It is not enough just to focus on bottom up approach. One can upscale and go one with the process but it will not hit the mark. One has to follow a top-down approach, i.e., to learn from the heterogeneity. Our aim should to be to attain excellence and not perfections. Processes happen at all scales. We need to ask ourselves, where does process of interest for decision making happen in ground-water and challenge ourselves to come up with models for solving those issues.

Discussion

MK - We have not understood recharge mechanisms at all, for example, soil moisture accumulation and associated drainage.
PM – A combination of process understanding which is physics- based as well as application of simple numerical and statistical models is required.
SR - We have to ask ourselves, do we need to look at same metrics for example R^2 at all scales.

Development of high resolution multi scale soil moisture information – by Prof. Karthikeyan Lanka

- This research sits at intersection between surface water - groundwater - remote sensing.
- The rooting depth varies as per crop type and growth stage and percentage of water intake varies. But soil moisture mission provides data only for top 5 cm for drought analysis. SMAP gives 0 to 5 cm, 0 to 100 cm at 9 km resolution.
- The work focusses on disaggregation of 9km product at 1 km level.
- In the study analysis for United States, the area was divided into regions where soil moisture relationship is going to hold true and those were used to set up relationships and predict for ungauged grids.
- Co-variate analysis showed that meteorological conditions really didn't play a role to explain the differences. Geomorphological features such as soil depth, pore density etc. were found to be major driving parameters.

Comments - MS - Use a top-down model for disaggregation/scaling framework. If you have catchment scale water depth it allows you to disaggregate at average scale to water

table depth using bridge. E.g., TOPMODEL by Keith Bevan helps in obtaining the equilibrium soil moisture profile from Digital Elevation Models.

Scale issues in high resolution remote sensing for land surface modeling - by Dr. Debsunder Dutta

- When studying trends of temperature anomalies contributing to climate change, we see that scale issues appear – on a log plot, if we see the rate at which we are warming, it is at an unprecedented rate.
- To understand land atmospheric interactions, which are tightly coupled, we use using remote sensing. If we add spectral scale to remote sensing, how can it help us develop better understanding?
- Some signatures get lost in hyperspectral remote sensing – for example – daily hydrograph. It is interesting to understand how light is interacting with canopy. Newer paradigms of how remote sensing can help us - for example it can provide insights into functioning of processes of photosynthesis which are highly coupled can be studied. Some parameters are constant and so can be overlooked at large scale. Thus, emergent phenomena which we see in the nature can be studied using remote sensing.

Multilevel modelling approach to estimate irrigation withdrawal - by Dr. Rajarshi Bhowmik

- The study used USGS datasets at county level for estimating irrigation water withdrawals. A simple regression model with only one intercept term for entire nation would not be able to capture the interstate variability. So we should come up with different regression models for different scales.
- Results showed that climate has least impacts for irrigation water use. It can be due to the fact that most of the impacts due to other causal factors had been mitigated due to sprinkler and increasing groundwater exploitation.

Comments – MS – It is not a right way to conclude and attribute the effects to climatic factors as it is a social rather than climate problem.
MK - One should think from production side also rather than climate side/supply side.

3.2. Breakout session

Breakout Groups

Space Scales	Time Scales	Space-Time Scales	Scale Effects Due to Human Interventions
Nagesh Kumar	Balaji Narasimhan	J. Indu	Mohan Kumar
Sagar Chavan	Argha Banerjee	Deepak Bisht	Debsunder Dutta
Neha Khandekar	Nitesh Patidar	Lakshmikantha	Shylza Sharma
Pankaj Dey	Walter Samuel	Rajarshi Bhowmik	Kaushika G S
Seetha Narayanan	Karthikeyan Lanka	Ila Chawla	Satish Regonda
	Gowri R		

Group 1 – Space Scales

Scale	Floods	Runoff	Soil Moisture	Suitable Models
Hillslope	slope, time of interaction	Topography	Less influence	GIUH, Conceptual
Catchment	river network, time of interaction (urban – social)	Rainfall characteristics, intra and inter storm variability,	Coupling of water pathways	Conceptual
River basin	river network, interaction between processes	river network, interaction between processes	Coupling of water pathways	Distributed
Regional (coupling of factors)	+ climatic factors	Competition between energy and water	Coupling of water pathways	Distributed

- Challenges are to figure out models for input parameters at different scales and coupling of models at different scales.

Group2: Time Scales

- The processes of the hydrologic cycle occur at different time scales. One of the important variables is the soil moisture which is directly related to the other processes of the hydrologic cycle.
- Soil moisture has an associated memory which is important in bridging information across different time scales.
- Soil moisture is considered as a system is forced by precipitation from above, evapotranspiration, irrigation, topography, etc., which have their own range of time-scales. The variation of the soil moisture is a response to these forcings.
- Hypothetically, if we are able to obtain soil moisture at 1 m scale, we now need to understand at what time scale these measurements would be actually useful to understand the micro pore and macro pore processes.
- Knowing the forcings, the response is controlled by the transfer function which potentially has multiple time scales. We can compute the transfer function (say Fourier transform function). Soil moisture can be aggregated over different spatial scales and the transfer function can be computed for each of these.
- As we go to larger spatial scales, the inherent multiple time scales of the transfer functions, how would these changes, do they merge into one?
- As we upscale from finer to coarser time scale, where would the effect of multiple time scales can still be observed which would help us to describe the processes and in turn parameterize the models?

Group3: Space-Time

- Processes of interest at various scales in India are: Precipitation, runoff, vegetation, soil moisture.
- IC - Dealing with streamflow, scale varies from catchment scale to regional (say in Ganga basin for example, the scale ranges from few kms to lakhs of sqkms. Temporal scale of interest for streamflow (point variable), that depends on rainfall (spatial variable) may vary from daily and monthly for streamflow.
- RB - Interaction between atmosphere variables, land surface (sub-surface and surface) process is interesting to study.
- DB - For processes like spring discharge, finer temporal resolution like hourly is preferred. Water management at basin scale is mostly studied at daily resolution.

  LN - For looking into watershed intervention (land use type/ manmade structure), one needs to look at different temporal

- scale like daily or monthly for atmosphere/ groundwater and hourly scale for surface water storage and water usage in agriculture landscape.
- Observation scale, be it spatial and temporal, is objective and process driven constraints by limitation of measurement. E.g. Diurnal pattern of spring discharge, flood peaks, land-atmosphere interaction. Nature of heterogeneity or variability or organization and their dominant control.
- RB - Heterogeneity lies from the management scale say field scale to watershed scale and sub-surface and surface process the variability is quite high.
- IC - Variability is prevalent at both spatial and time scale. It is required to understand how the process evolves while going to higher scale, be it spatial or temporal. Heterogeneity of the process in temporal and spatial scales very much affects the overall response of the system.
- Scale Problem is usual with upscaling and downscaling of data. Bottom up and top down approached depends upon the process under consideration, data availability and the scale at which data availability. Many information gets lost at larger scale, however many time process that are very important at smaller scale do not play very decisive role in regional scale, says infiltration process at plot scale.
- RB - Heterogeneity at watershed scale and atmosphere scale is quite different in scale and time. For temperature spatial variability is lesser compared to precipitation, this makes the interaction much complex.
- IC - For streamflow, soil moisture and rainfall both are major drivers. Soil moisture varies at sub-daily scale, LULC varies at five yearly or decadal scale. While modeling streamflow at daily scale, LULC may not change at daily scale but other parameters that represent LULC say LAI changes at weekly scale.
- LN - Feedback time should also be considered while discussing the scale interaction.
- DS - How the scale interaction can be incorporated into a hydrological modeling framework? Are we really heading towards coupled modeling framework instead of stand-alone hydrological modeling framework to address the land-atmosphere interaction?
- The drivers of atmosphere and hydrology operate at different scale therefore, their interaction becomes more complex.
- DB - Parametrization scheme through calibration may take care of spatial heterogeneity but how to deal with the temporal heterogeneity becomes an issue.
- IC - Dynamic parameters are required in both space and time to address the heterogeneity and changing conditions.
- There is a need to search for new laws and have mechanisms to incorporate feedback as a variable. Dynamic parameterization in both space and time under changing conditions is needed.

Group4: Human intervention in space - time scales in hydrology

- Human intervention like bunds, farm ponds, reservoirs exist at different scales. They have both positive and negative effects. The hydraulic conductivity changes with pore structure.
- It is interesting to observe changes in hydrological cycles due to human interventions, e.g., for urban areas, response is faster and distribution of residence time varies between urban and catchment scale. Water flows through these man-made flow paths and there are inter-basin transfers as well as conflict in water sharing. Feedback mechanisms need to be studied in this case.

Associated processes	**Variables**
Infiltration	Soil moisture
Base Flow	GW table
Overland flow	Water quality
Flow in rivers	Effective discharges from Ecological life

- DD - Nature of heterogeneity is changing at a faster scale. In terms of space-scales, there are drastic changes at small scales. Eg: urbanization.
- SR - Streamflow in case of urbanization is heavily influenced by people. Decision variables need to be determined to work out feedback mechanisms. Also the policy makers are interested in impacts across different time scales while a layman qill be interested in getting more information about localized processes.
- MK - Lawmakers' influence on the decisions.
- How to include the human intervention in a model is an interesting question to wonder about?
- SS - it might be useful to study change in urban area as a covariate with the extreme events.
- MK- Water supply planning (future thoughts) based on transport /logistics availability/approachability. There are both positive/negative effects of implementation of irrigation system. In a catchment scale, demand points are based on human intervention/urbanization. There are transboundary disputes, Heat Islands (high urban state), different issues in peri-urban areas etc.

- SR - Problem influences scales. In a farmer's context, use of irrigation water can be from wells owing to water supply in the region. Such thoughts based on one person's decision brings heterogeneity. Farmland bunds influence the local water flow in farms/systems. These affect river flows.
- MK - There are water quality issues at local and regional scales as well due to human interventions like groundwater contamination and pathogen movements. Field bunds are necessary and can be better managed by irrigation procedures.
- KA - Reservoir/changes in the water systems affecting the ecology.
- MK - There is rise in ground water extraction processes. Dam releases causes artificial floods. Thus it becomes all the more important to understand the connectivity between surface and ground water.
- SS - Effect of GW extraction on subsurface pore/fracture structure needs to be studied. Influence area of floods increased based on the urbanization. Dam/reservoir design capacity should also consider urbanization effects.
- SR - Links between surface/ground water may result in increased/decreased baseflow. Increase in the frequency of floods need to be studied.
- LN - Who decides social or economic costs of interventions? There are normative concerns. It is better to let the society decide the usefulness of the structure rather than researchers.

4. Way forward – Day 3

The workshop was closed by remarks and suggesting way forward by Professor Sivapalan and Prof Mujumdar. Prof Sivapalan said that this meeting was only the first step, not the end but the beginning of thinking. This workshop helped us to get the language, as goes famous quote by Ludwig -

'The limits of my language are the limits of my mind. What I know is what I have words for…'

The conversations in breakout sessions helped at getting the language right. The success of a workshop can be gauged by asking two questions -

1. Have I learnt anything?
2. Did I get energized and feel that there is so much to do?

Can we aspire to bring a new beginning for the study of scales and make India the focus point and bring international delegates here? The question is how we get there.
We should work as a team and collaborate more among Indian universities – the importance of team science and the culture of openness.
As Indian hydrology community, we should aspire to lead the world, be big, bold ambitious, and see the light at the end of the tunnel - the 2021 workshop.
A high school teacher told me -
'If we want to become equal to someone / before you can become equal to someone, you have to be superior.'
'If you don't know where you are sailing to, no amount of wind can help you…'
Thus, if you don't know where you are going, no amount of data can help you.
So we should not only aspire for organizing the next scale international workshop in hydrology but also produce two concrete outputs, two major group efforts; <u>using soft hands of a batsman</u>, get the big picture right and then start filling the details to get agreement on the big picture.

It was decided that an international conference on scale issues will be organised by the end of the year 2021, which will be led by Indian water community. The outcomes from the current discussion meeting need to serve as the precursor for the future conference/meeting. The key takeaways/outcomes from the current meeting to be availed in that conference are:

1. Review paper - structure - space, time, space-time in natural and human dominated context (referring Bloschl and Sivapalan, 1995)

2. Not just science but also use science to solve problems - a white paper that outlines societal problems that India faces (can serve as a blue print), a forward looking document which will is widely accepted and it can be used to obtain funding.
3. Twenty articles based on individual work which will be done by the participants.

PM assured that IISc Bengaluru will facilitate collaborative workshops. Write-shops in smaller groups are to be organized at IISc.
Indian problems can give significant variation to study and analyze and to add to the knowledge bank and hence, we should not hesitate to work on the Indian problems. The papers collected from previous workshops will be mailed to all the participants.

PM – about the writing team – efforts has to be taken to higher levels, otherwise what we have done till now becomes a criminal waste. We will organize a workshop on scale issues in 2021 in which 50% participation will be from Indian side and 50% from foreign researchers. For the paper writing, assistant professors from IITs are entitled to lead and form groups. The suggested coordinators are Dr. J. Indu (IIT Bombay) followed by Dr. Argha Banerjee (IISER Pune), Dr. Seetha Narayana (IIT Hyderabad), Neha Khandekar (ATREE Bangalore), Dr. Karthikeyan Lanka (IIT Bombay) and Dr. Satish Regonde (IIT Hyderabad).

The meeting concluded with more discussions on the transit with hope to resolve and study the Scale issues in Hydrology and to meet the goals planned.

5. ANNEXURE

5.1. Annexure A: Agenda

Discussion Meeting on

"Scale Issues in Hydrology"

1-3 December, 2019

Day 1: Sunday, December 1, 2019 **Venue: Hoysala Village Resort, Hassan**		
3:30 PM	3:35 PM	Welcome Note – Prof. P P Mujumdar
3:35 PM	4:30 PM	Participants' Self-introduction (2 minutes each)
4:30 PM	5:00 PM	Overview of the Science Issues – Prof. Sivapalan
5:00 PM	6:00 PM	Open Discussion
Group Outing to Ancient Hoysala temples of Belur and Halebidu		

Day 2: Monday, December 2, 2019 **Venue: Hoysala Village Resort, Hassan**		
Session 1 – Short Presentations (8 minutes presentation + 2 min discussion each) Chair: Prof. Mohan Kumar, IISc, Bangalore		
9:30 AM	9:40 AM	Prof. Mohan Kumar, IISc Bangalore
9:40 AM	9:50 AM	Dr. Balaji Narasimhan, IIT Madras
9:50 AM	10:00 AM	Dr. Satish Rengoda, IIT Hyderabad
10:00 AM	10:10 AM	Dr. Argha Banerjee, IISER Pune
10:10 AM	10:20 AM	Prof. J. Indu, IIT Bombay
10:20 AM	10:30 AM	Dr. Sagar Chavan, IIT Ropar
10:30 AM	11:00 AM	Open Discussion
Session 2 (11:30 AM – 1:00 PM) – Discussion in Breakout Groups		
1:00 PM	1:30 PM	Report from Breakout Groups & Discussion
Group Outing to Silk manufacturing unit		

Day 3: Tuesday, December 3, 2019 **Venue: Hoysala Village Resort, Hassan**		
Session 1 – Short Presentations (8 minutes presentation + 2 min discussion each) Chair: Prof. Nagesh Kumar, IISc, Bangalore		
9:30 AM	9:40 AM	Prof. Nagesh Kumar, IISc Bangalore
9:40 AM	9:50 AM	Dr. Seetha Narayan, IIT Hyderabad
10:00 AM	10:10 AM	Dr. Karthikeyan Lanka, IIT Bombay
10:10 AM	10:20 AM	Dr. Debsunder Dutta, IISc Bangalore
10:20 AM	10:30 AM	Dr. Rajarshi Bhowmik, IISc Bangalore
10:30 AM	11:00 AM	Open Discussion
Session 2 (11:30 AM – 1:00 PM) – Discussion in Breakout Groups		
1:00 PM	1:30 PM	Report from Breakout Groups & Discussion
2:30 PM	3:30 PM	Final Discussion Session Coordinated by Prof. Sivapalan
Group Outing to backwaters of Gorur Dam with submerged church		

5.2. Annexure B: List of participants

Name	Institute	Research Area/ Interests
Prof. Murugesu Sivapalan	Professor, UIUC, Urbana-Champaign, USA	Scale issues in hydrology, PUB, Socio-hydrology
Prof P. P. Mujumdar	Professor, IISc Bangalore	Scale issues, urban hydrology, compound extremes, impacts of climate change, reservoir operations and planning
Prof. M. S. Mohan Kumar	Professor, IISc Bangalore	Groundwater flow modeling, Flow through the vadose zone, Contaminant transport modelling in porous media, Flow in canal networks, Multiphase flow modeling, Water quantity / quality modeling in distribution networks
Prof. D. Nagesh Kumar	Professor, IISc Bangalore	Remote sensing and stochastic modelling for irrigation operations in reservoir modelling , neural networks, optimization tools for multi-purpose dam projects, hyperspectral remote sensing for crop yield modelling, climate change impacts, addressing scale issues in hydrology
Prof. Balaji Narsimhan	Professor, IIT Madras	Inverse modelling, flood forecasting system, Urban modelling, scale issues in remote sensing estimations
Dr. Satish Regonda	Assistant Professor, IIT Hyderabad	Modelling in data poor region Statistical model and community based data, Science - communication using GUI, scale issue in drones for data, transferring scientific understanding to decision making
Dr. Argha Banerjee	Assistant Professor, IISER Pune	Glaciology, field based estimations and data to understand the glaciated basins, large scale modelling
Dr. J. Indu	Assistant Professor, IIT Bombay	Remote sensing in Civil Engineering, microwave based radar for agriculture data and

		for engaging with uncertainty in precipitation, soil moisture, satellite data – transferability to ungauged basins
Dr. Sagar Chavan	Assistant Professor, IIT Ropar	Using geo-morphologic based unit hydrographs, probable maximum precipitation inputs, self-similarity property of river networks for predictions in ungauged basins, sedimentation issues , frequency of extreme events, impacts of climate change
Dr. Seetha Narayana	Assistant Professor, IIT Hyderabad	Colloid transport in porous media and associated scale issues - experiments to develop better models
Dr. Karthikeyan Lanka	Assistant Professor, IIT Bombay	Soil moisture analysis using satellite estimations, downscaling RS soil moisture to finer spatial scales, root zone soil moisture retrieval, soil moisture and precipitation feedbacks in Indian scenario.
Dr. Debsunder Dutta	Assistant Professor, IISc Bangalore	Hyperspectral remote sensing for applications like forecasting Indian monsoon, improving parameterization and hydrological modelling using finer resolution sensor data, improve process understanding ecosystem to improve prediction, climate modelling
Dr. Rajarshi Bhowmik	DST INSPIRE Faculty, IISc Bangalore	Biometeorology, implication of rainfall events in Indian context, Simulation/validation of unprecedented events, stochastic models for predicting non-stationarity
Ms. Neha Khandekar	Research Scholar, ATREE Bangalore	Water conflicts- conflicts at scale (space-time), socio-hydrology
Mr. Lakshmikantha NR	Research Scholar, ATREE Bangalore	implications of watershed interventions across scales - plot, milli-catchment, sub-catchments, basin level
Dr. Kaushika G S	Post-doctoral Research Associate, IISc Bangalore	Modelling of Vadose Zone processes (Root water uptake) under changing climate, SWAT modelling for upper Ganga basin including

		snow modelling, time scale and space scale problem in Upper Ganga basin, urban flood management in Bangalore
Ms. Gowri R	Research Scholar, IISc Bangalore	Hydrologic modelling, scale issues, impact of interventions, hydrologic signatures in Cauvery basin
Ms. Shailza Sharma	Research Scholar, IISc Bangalore	Hydro-climatic extremes, multivariate stochastic models, models to improve characterization of extremes – droughts in Maratwada and Vidarbha, flood forecasting models for Uttarakhand
Dr. Ila Chawla	Post-doctoral Research Associate, IISc Bangalore	Impacts of land use changes on water resources in Western Ghats , integrated and isolated impacts of land use and climate into hydrology using Variable Infiltration Capacity model, transferability of model parameters into time and space scales
Mr. Pankaj Dey	Research Scholar, IISc Bangalore	Catchments as complex systems, emergence and self-organization phenomena, memory of processes in complex adaptive system, emergent phenomena
Mr. Walter Samuel	Research Scholar, IISc Bangalore	Isotope hydrology , physio-chemical characteristics in Brahmaputra river basin
Dr. Deepak Singh Bisht	Scientist B, NIH WHRC - Jammu	Urban drainage design, flood modeling, climate change impact analysis, spring hydrology, socio-hydrology
Mr. Nitesh Patidar	Scientist B, NIH Roorkee	Satellite remote sensing, optical datasets and machine learning techniques, temporal variability of land cover in hydrology, urban catchments impacts on hydrology
Ms. Susmita Raha	S.A., IISc Bangalore	