INTERNATIONAL ASSOCIATION OF HYDROLOGICAL SCIENCES

IAHS Decade on Predictions in Ungauged Basins (PUB): 2003-2012

PUB Science and Implementation Plan

Penultimate Draft for Discussion (Version 4), prepared by:

PUB Science Steering Group (SSG)

Critically reviewed by:

PUB Strategic Advisory Group (SAG)

June 24, 2003

Background to IAHS PUB

IAHS is an international association for hydrological sciences established in 1922, having over 3000 members around the world. As a science association IAHS is engaged in various activities to enable science to serve society. Predictions in Ungauged Basins (PUB) is the most recent initiative of the IAHS, a celebrated policy-relevant science initiative that arose out of free discussion by IAHS members on the World-Wide Web and during a series of IAHS sponsored meetings at Maastricht, Kofu and Brasilia, based on the recognition of current needs of the world, especially of developing countries, and a scientific readiness to make a new commitment.

PUB Strategic Advisory Group (SAG)

Kuniyoshi Takeuchi (Chair), Lars Gottschalk, Jim Shuttleworth, Pierre Hubert, Jim Wallace and Murugesu Sivapalan will serve as initial members and eventually those who belong to the following categories will join:

a. Experienced international scientists and senior representatives of stakeholder scientific groups.
b. Linkage coordinators for IHP & WWAP (UNESCO), HELP & FRIEND (IHP), WCRP & HWRP (WMO), WHYCOS (HWRP), GEWEX (WCRP), CEOP (GEWEX), IAEA, MOPEX, CHASM

SAG Terms of Reference:

The SAG is responsible for:

1. Providing advice on and periodic review of the planning and implementation of PUB activities.
2. Fostering and managing effective linkages to related programmes.
3. Securing funds for PUB through lobbying of national and international funding agencies.
4. Planning and implementation of capacity building activities within PUB.
5. Developing strategies for implementing the outcomes of PUB for societal benefit.

PUB Science Steering Group (SSG)

Murugesu Sivapalan (Chair), Stewart Franks, Harouna Karambiri, Venkat Lakshmi, Xu Liang, Jeff McDonnell, Mario Mendiondo, Taikan Oki, John Pomeroy, Daniel Schertzer, Stefan Uhlenbrook.

Terms of Reference of SSG

1. The SSG shall carry primary responsibility for leading, planning, and implementing the PUB initiative, especially with regard to scientific aspects of the program.
2. The SSG shall coordinate PUB activities with all IAHS Commissions and other global programmes (e.g., HELP, FRIEND, GEWEX, CEOP).
3. The SSG shall submit the PUB Science and Implementation Plan to IAHS at the IUGG General Assembly at Sapporo in July 2003, and on approval, publish it in the Hydrological Science Journal during 2003.
4. Appointment to the SSG is initially until mid-2005.
5. Additional members may be co-opted into the SSG as may be necessary to complete assigned tasks.

Acknowledgements:

This report was produced through detailed discussions within PUB Science Steering Group (SSG), and through extensive consultations with a wide range of hydrologists from around the world, too numerous to mention here. Their enthusiasm and active support are gratefully acknowledged.

Foreword

It is now almost two years since the IAHS Bureau unanimously approved the PUB initiative in July 2001. We first assembled in Kofu in March 2002 for the preparation of a draft plan, which was endorsed by the IAHS Bureau in June 2002. In November 2002 we held a PUB kick-off workshop in Brasilia, where the PUB Science Steering Group (SSG) and the Strategic Advisory Group (SAG) were formed. The SSG then drew up a draft PUB Science and Implementation Plan and presented it in Kyoto in March 2003 on the occasion of the 3rd World Water Forum, during which the broad outlines of the plan were enthusiastically received. The present document is the subsequent version of the Science and Implementation Plan, revised and updated by the SSG in response to comments and suggestions from a broad cross-section of scientists, and reviewed by the SAG, and will be presented during the PUB Workshop HW07 at the IUGG/IAHS General Assembly to be held in Sapporo in July 2003. I sincerely hope that the Plan will be endorsed there both by the IAHS Bureau, as well as by the General Assembly. It will then be time to start the real work.

PUB is a policy relevant science endeavour aimed at reducing the uncertainty in hydrological predictions, and is expected to become the basis of sustainable management of water resources throughout the world. PUB welcomes any approach so long as it focuses on the reduction of predictive uncertainty. It embraces all branches of hydrology from water quantity to water quality, surface water to groundwater, snow and ice to continental erosion, basic theory to water resources applications, and so forth. PUB invites all the hydrologists of the world to participate in its activities, either individually, or through affiliated working groups and other national and international programmes. In particular, we expect and encourage all IAHS International Commissions to take up key roles in the implementation of PUB scientific programmes, and in the delivery of the outcomes of research to the user community, including other programmes that link hydrologic predictions to water resources management and policy. Let us all work together on PUB with excitement for the science and the benefits it brings to society, and help fulfil our societal mission.

I appreciate all those who have supported PUB so far through their comments, constructive criticism, and encouragement, with special thanks to Prof. Murugesu Sivapalan, the SSG chair, for his devotion and dedicated leadership on the creation of this plan.

Kuniyoshi Takeuchi
Chair, PUB Strategic Advisory Group (SAG)
President, International Association of Hydrological Sciences (IAHS)

Preface

While PUB has been enthusiastically received right from the outset, opinions about the definition and scope of PUB have been sharply divided and strongly held. Through continuous discussions and debates over the past two years these differences have been reconciled. We have now come up with a Science and Implementation Plan that is inclusive, pluralistic and focused on the idea of reduction of predictive uncertainty. Yet, while PUB embraces a plurality of approaches and applications, it does not mean “all things to all people” nor is it “business as usual”. Through insistence of a key a set of constraining elements PUB will retain a high level of coherence, with excellent chances for significant breakthroughs.

PUB is, first and foremost, a scientific endeavour, and this is reflected strongly in this plan. Yet, through partnership with programmes such as HELP, FRIEND, GEWEX, CEOP etc., it will establish links to users, and help make a real difference to sustainable development, fully meeting the societal obligations of our science. An important contribution of PUB, apart from improved predictive capability, will be capacity building, which will be achieved through targeted global partnerships and outreach activities.

PUB is a grassroots level mass movement, not a top-down or trickle-down initiative driven by the IAHS Bureau or even by the SSG/SAG. The main role of the SSG will be the coordination of PUB activities to maintain coherence and retain its focus. The main engines of PUB, however, will be you the scientists and practioners, coming together in self-organised fashion, to form affiliated PUB Working Groups, or individually or in small groups making a contribution through Individual Projects. With this document I make an open call to all hydrologists worldwide to either form PUB Working Groups and/or Individual Projects, and register them with the SSG. PUB will be inclusive of all scientific programmes and activties that have a commitment to reducing predictive uncertainty, through comparability of different approaches, and assimilation of different sources of information and forms of knowledge and learning.

Murugesu Sivapalan

Chair, PUB Science Steering Group (SSG)

Guide to Abbreviations

AGU	American Geophysical Union
ATSE	Australian Academy of Technological Sciences and Engineering
BHS	British Hydrological Society
CEOP	Coordinated Enhanced Observing Period
CHASM	"Catchment Hydrology and Sustainable Management" project
DMIP	Distributed Model Inter-comparison Project
EGU	European Geophysical Union
FRIEND	Flow Regimes from Experimental and Network Data
GEWEX	Global Energy and Water Cycle Experiment
HELP	Hydrology for the Environment, Life and Policy
HESS	Hydrology and Earth System Science journal (EGU)
HP	Hydrological Processes journal
HSJ	Hydrological Sciences Journal
HWRP	Hydrology and Water Resources Programme
IAEA	International Atomic Energy Agency
IAHS	International Association of Hydrological Sciences
iEMSs	The International Environmental Modelling and Software Society
IHP	International Hydrological Programme
IP	PUB Individual Projects
IUGG	International Union of Geodesy and Geophysics
LOCAR	Lowlands Catchments and Rivers Project
MODSIM	International Congress on Modelling and Simulation
MOPEX	Model Parameter Estimation Experiment
PUB	IAHS "Decade on Predictions in Ungauged Basins" Initiative
SAG	PUB Strategic Advisory Group
SSG	PUB Science Steering Group
UNESCO	United Nations Educational Scientific and Cultural Organisation
USLE	Universal Soil Loss Equation
WCRP	World Climate Research Programme
WHYCOS	World Hydrological Observing System
WG	PUB Working Groups

WMO	World Meteorological Organisation
WWAP	World Water Assessment Project

International Association of Hydrological Sciences (IAHS)

IAHS Decade on Predictions in Ungauged Basins (PUB): 2003-2012

PUB SCIENCE AND IMPLEMENTATION PLAN
EXECUTIVE SUMMARY

Introduction

Sustainable management policies are needed to provide water not only for life, health and development but to prevent further ecosystem degradation, and to reduce the severity and impacts of natural hazards and disasters. We need a variety of predictive tools that can generate predictions of hydrologic systems, over a range of time and space scales, to underpin sustainable management of river basins from economic, social and environmental perspectives. Currently, the most widely used predictive tools for water resources, water quality and natural hazards assessments are essentially data-driven, estimated from hydrometric (gauged) data. Major difficulties are encountered when applying these traditional prediction tools to river basins for which little or no hydrometric data are available. In particular, the lack of hydrometric data coupled with the effects of climatic and land use changes contribute to considerable uncertainties in hydrologic predictions and in subsequent water resources and water quality assessments.

The IAHS Decade on Predictions in Ungauged Basins (PUB) is aimed at formulating and implementing appropriate science programmes to engage and energise the scientific community, in a coordinated manner, towards achieving major advances in the capacity to make predictions in ungauged basins. The science programmes within PUB will have the following broad community objectives:

1. Advance the ability of hydrologists worldwide to predict the fluxes of water and associated constituents from ungauged basins, along with estimates of the uncertainty of predictions;
2. Advance the knowledge and understanding of climatic and landscape controls on hydrologic processes occurring at all scales, in order to constrain the uncertainty in hydrologic predictions;
3. Demonstrate the value of data for hydrologic predictions, and provide a rational basis for future data acquisitions, including alternative data sources, by quantifying the links between data and predictive uncertainty;
4. Advance the scientific foundations of hydrology, and provide a scientific basis for sustainable river basin management.
5. Actively promote capacity building activities in the development of appropriate scientific knowledge and technology to areas and communities where it is needed.

PUB Science and Implementation Plan

The PUB Science Plan is divided into a) targeted and b) enabling research programmes. The targeted research programme is a time-bound programme of activities focused on three research targets, which will be achieved through the execution of seven (7) self-contained core research projects.

Target 1: **Evaluate the performance of existing hydrological models and prediction techniques in terms of predictive uncertainty.**

PUB will establish a new scientific framework for evaluating the performance of existing hydrological models and prediction techniques that are, or could be, used in ungauged basins, in the context of the uncertainty in their predictions. The relative importance of factors controlling predictive uncertainty will be investigated, namely, climate inputs, landscape properties and model parameters, and model structure and process descriptions. In the short term, PUB will also quantify, in a more scientifically rigorous

manner than done heretofore, the inadequacies of existing models and modelling approaches so as to provide signposts for new scientific developments.

Target 2**: Demonstrate the value of data, knowledge and understanding for reducing predictive uncertainty**

PUB will demonstrate the value of alternative types of data, knowledge and process understanding for reducing predictive uncertainty, thus providing guidance for data collection programmes, new remote sensing developments, and new ground–based instrumentation and targeted field experiments, and for using widely available digital data sets effectively for predictions. Advances in data availability, knowledge, and process understanding will be utilised towards targeted efforts to reduce the uncertainty in the longer-term.

Target 3**: Understand the hydrological functioning of basins at different scales in different hydro-climatic regions**

PUB will have a major thrust to understand the hydrological functioning of basins at different scales, to identify which processes are dominant or controlling at different scales in the different hydroclimatic regions of the world, to determine how hydrologic functioning controls, or is constrained by, ecological functioning and atmospheric exchanges, to estimate fluxes of water, sediments and nutrients to the oceans etc, and to determine how human activities can impact on the functioning of basins and associated ecosystems. PUB will also explore how the strengthened scientific and predictive capability will contribute to improved management of water and the environment.

PUB Core Research Projects

A suite of eight highly focused PUB Core Research Projects has been developed to achieve these targets by the end of the IAHS Decade, and will be the vehicles for the achievements of the core PUB objectives.

- Project for the Comparison of Uncertainty Estimation Methods
- Project for the Comparability and Harmonisation of Models and Prediction Approaches
- Project for Uncertainty Reduction through Assimilation of Data, Knowledge and Understanding
- Project for Hydroclimatic Classification of Basins and Harmonisation of Prediction Methods
- Project for Virtual Collaboratories and Field Experiments
- Project for Prediction of Effects of Natural Climatic Variability and Climate and Land Use Changes
- Project for Enhancement of Data Collection and Assimilation Programmes
- Project for Capacity Building Programmes Through Global Partnerships

Enabling Research Questions

The enabling research programme refers to fundamental research that is directly relevant to PUB, and is articulated through the following six science questions:

- What are the key gaps in our knowledge that limit our capacity to generate reliable predictions in ungauged catchments?
- What are the information requirements to reduce predictive uncertainty in the future?
- What experimentation is needed to underpin the new knowledge required?
- How can we employ new observational technologies in improved predictive methods?
- How can we improve the hydrological process descriptions that address key knowledge elements that can reduce uncertainty?
- How can we maximise the scientific value of available data in generating improved predictions?

PUB Organisational Structure

PUB aims to mobilise the entire worldwide hydrological community to achieve its stated objectives through research, educational and outreach activities. The proposed structure for PUB research activities has been aimed at fostering a flexible, self-organising framework which …

- is inclusive of the diverse range of research interests within the hydrologic scientific community, and a similarly wide range of applications;
- amenable to the adoption of uncertainty estimation on a routine basis;
- enables comparability of the performance of a plurality of approaches with regard to specific objectives;
- encourages the integration of different areas of expertise towards specific common objectives;
- emphasizes the merging or assimilation of theoretical advances, process understanding, new data technologies and evaluation of model performances in different contexts (scales, applications, hydro-climatic zones etc.) towards the reduction of predictive uncertainty; and
- through insistence of these fundamental organizing principles in the conduct of the various science programmes within PUB, helps to unify and harmonise the hydrological community for rapid advances of the science and its societal relevance.

PUB Working Groups and Task Forces

PUB research will be carried out through a global network of Working Groups (WGs) comprising interested researchers in any area of prediction in ungauged basins, cutting across traditional thematic areas (such as remote sensing, field-based approaches, theoretical developments, calibration, model evaluation, etc.). Indeed, WGs will be the main engines PUB research activities. WGs shall define their own objectives but will be required to have an emphasis on enabling comparability of different approaches towards well-defined common goals, including reduction of predictive uncertainty. The emphasis on comparability of activities within and between WGs is aimed at value adding to individual research efforts, and helping to harmonise and reach consensus, in approaches to making hydrologic predictions.

PUB and PUB-Sponsored Activities

The global range of PUB and PUB-sponsored activities will be coordinated by the Science Steering Group (SSG), which will also actively seek to form links with existing national, regional and international groupings, international programmes as well as IAHS commissions, to capitalise on potential synergies for the advancement of PUB.

The SSG will proactively work towards enhanced coordination amongst the many PUB Working Groups that will be formed around the world centred on basins, problems, hydroclimatic regimes etc. In order to facilitate this, and provide greater coherence and grass-roots involvement, the SSG will actively work to form a number of Project Task Forces, one for each of the PUB Core Projects outlined above, with representatives taken from the various Working Groups, and one representative from the SSG, the latter acting as Interim Convenor. In due course, however, we would expect the SSG to reconstitute itself mainly with representatives from the various Task Forces, with only a few actually appointed by the SAG.

As PUB research takes hold, the main PUB activities will be in three areas:

1) organization of meetings, workshops and congresses,
2) regular publication in journals, reports and books, of progress in PUB activities, and
3) Technology Transfer through various means, but with a specific focus on web-based communication.

Role of and Links with IAHS Commissions

We expect and encourage all IAHS International Commissions, in partnership with the SSG, to take up key roles in the implementation of PUB scientific programmes, and in the delivery of the outcomes of

PUB research towards improved water resources and water quality management. PUB will certainly benefit from the diversity of disciplinary strengths, experience and organization contained within each of the IAHS Commissions, as they are more focused towards addressing the fundamental science questions of the PUB research programme. These may relate to different sub-disciplines of hydrology dealing with land-atmosphere interactions, water quantity, water quality, surface water, groundwater, snow and ice, continental erosion, and observational (remote sensing, tracers) and theoretical hydrology. In addition, it is envisaged that a few IAHS Commissions, either individually or in partnership with other Commissions, will form affiliated PUB Working Groups to carry out integrative research, targeted towards reducing predictive uncertainty in specific applications, river basins, or geographic or hydroclimatic regions.

Links to Other International Programmes

PUB will link up, and closely coordinate its activities, with other basin-scale and planetary-scale programmes such as HELP, FRIEND, WWAP, WHYCOS, GEWEX, and CEOP, to share data, resources and expertise, and to participate in joint activities, such as the meso-scale and larger scale field experiments being organised by HELP and GEWEX. It is envisaged that at least some of the HELP/FRIEND, GEWEX/CEOP basins will be adopted as PUB basins by PUB Working Groups, provided that the available data is of adequate quality for PUB. In addition, due to the focus of HELP and FRIEND on applications of scientific advances for improved water management and policy, links with these programmes can advance the societal relevance of PUB outcomes. Links with the extensive international network of basins and scientists assembled under HELP, FRIEND, WWAP, WHYCOS, GEWEX etc. will also assist towards the capacity building objective of PUB, for the benefits of PUB to be shared and propagated towards the user community.

Roles of the SSG and SAG

The main role of the SSG is therefore to plan, lead, facilitate and coordinate all PUB activities, act as a catalyst for the formation of PUB Working Groups and the Task Forces associated with the PUB Core Research Projects outlined above, and provide avenues for the communication of the research outcomes to the wider hydrologic community through conferences, workshops, short courses and publications. The SSG is especially responsible for maintaining coherence of the entire PUB research programme, and will achieve this pro-actively through the coordination of several Project Task Forces, which will be the main instruments for driving the associated Core Research Projects. The SAG is a review or oversight body, and is especially responsible for lobbying and fundraising, fostering closer cooperation with other national and international programmes, and for developing and promoting capacity building activities through global partnerships and outreach.

PUB Outcomes and Benefits

- development of a framework for, and implementation of, routine estimation of predictive uncertainty in all future hydrological predictions
- a new suite of models and methodologies that can be used with confidence for predictions in ungauged basins in different hydroclimatic zones
- a network of scientists and groups around the world, especially in developing countries, with the necessary scientific expertise and experience to solve emerging hydrological problems
- an array of measurement networks in selected basins around the world and associated databases of hydrological measurements to serve as a reference pool for new emerging questions.

The benefits of PUB to society are increased capability to predict and manage water resources and water quality, a scientific rationale for measurements, and a harmonisation of models and modelling approaches. Benefits to science are greater coherence of the hydrologic science agenda, greater coordination and

harmony of scientific activities, and increased prospects for real scientific breakthroughs and therefore excitement for the science.

Hydrologic Predictions for River Basin Management

Across the globe, water resources and the water environment are under threat as never before. In river basins everywhere, human activities have disrupted the natural hydrological and ecological regimes. Water supplies are not secure for millions of people worldwide, flood risk is increasing, and biodiversity is steadily decreasing due to the ongoing destruction of riparian ecosystems. These impacts are felt not only locally, but are transmitted through land-surface feedbacks to disturb the climate itself, leading to increased severity of floods and droughts.

Our challenge is to identify appropriate responses to these threats. Sustainable management policies are needed to provide water not only for life, health and development but to prevent further ecosystem degradation, and to hopefully reduce the severity, frequency and impacts of natural hazards and disasters. Wise stewardship of water and environment requires a variety of predictive tools that can generate predictions of hydrologic responses over a range of space/time scales and climates, to underpin sustainable management of river basins, integrating economic, social and environmental perspectives.

Over the years, hydrology has tried to put into the hands of regulators, developers, and their designers the predictive tools (equations, mathematical models, computer codes) that allow objective and quantitative decision-making with respect to water resources and water quality management, as well as natural hazards assessments. The most widely used tools, such as unit hydrographs, flood frequency curves, flow duration curves etc. are essentially data-driven, and estimated from hydrometric (gauged) data at river basin scales. Application of these tools for extrapolative predictions in other basins is based on the premise that 1) the past is a reasonable guide to the future, and 2) data from any one basin, and models derived therefrom, are useful guides to estimating hydrological responses at another basin. Over the past three decades, there have been attempts to make some of these tools more rigorous and realistic representations of environmental processes, through incorporation of spatial and mechanistic aspects. However, the resulting, more sophisticated models also suffer from similar restrictive assumptions, especially when developed and/or parameterised through calibration with historical data from gauged basins. Consequently uncertainties in hydrologic predictions are large and, when applied to design, planning, regulation, and other decision-making, they tend to mislead the consumers of such predictions.

What is an Ungauged Basin?

An ungauged basin is one with inadequate records (in terms of both data quantity and quality) of hydrological observations to enable computation of hydrological variables of interest (both water quantity or quality) at the appropriate spatial and temporal scales, and to the accuracy acceptable for practical applications.

For example, if the variable of interest has not been measured at the required resolution or for the length of period required for predictions or for model calibration, the basin would be classified as ungauged with respect to this variable. Variables of interest can be, for example, precipitation, runoff, erosion rates, sediment concentrations in streamflow, etc., so every basin is “ungauged” in some respect.

Predictions in Ungauged Basins

Major difficulties are encountered when applying traditional prediction tools or models to river basins for which little or no hydrometric data are available. In view of the tremendous spatio-temporal heterogeneity of climatic and landscape properties, extrapolation of information, knowledge or understanding from gauged to ungauged basins is fraught with considerable difficulties and uncertainties. Due to nonstationarities in the basin responses, caused by multi-annual and multi-decadal fluctuations in climatic inputs (precipitation, radiation etc.) and human-induced changes in climate and land use, approaches based purely on past data are inadequate for making predictions into the future.

PUB is the considered response of the international hydrologic community to these significant challenges. PUB is a science initiative, and as such, is designed to provide the scientific underpinnings of sustainable river basin management in basins everywhere. It is intended that advances in hydrologic predictive capability resulting from PUB can be effectively utilized towards improvements in sustainable management of water resources and water quality, as well as anticipating and reducing the impacts of water-related natural hazards, in specific regions of the world. Towards this end PUB will establish direct links with existing international programs such as GEWEX, CEOP, HELP, and FRIEND, benefiting from these links to achieve major PUB objectives while, in return, adding value to these programmes through the improved predictive capability that arises from PUB.

Natural and Human-Induced Variability

A major concern for PUB is the increasing realisation that the statistics of locally observed hydrological variables are no longer stationary and may contain long-term trends caused by global-scale phenomena, and by land use changes at the local or regional scale. At the seasonal to inter-annual timescales, the influence of El Niño and La Niña on hydrological statistics (and the occurrence of extreme hydrological events such as floods and droughts) is now well recognised. These relationships (and others yet to be identified) can generate seasonal distortions in the statistics of hydrological variables, thus threatening the validity of the operational rules applied to water management systems.

There are also indications that the strength of important fluctuations in the global climate (such as those associated with El Niño and the La Niña) may themselves vary at the decadal timescale. Moreover, model studies suggest, and observational evidence tends to confirm, that an enhanced hydrological cycle is likely to be an important consequence of global climate change caused by "greenhouse warming”.

The consequence is that past hydrological records, when they are shorter than 30 years, are no longer reliable guides to what will happen in the future. Many standard procedures in hydrology are no longer valid under changing hydrological regimes, and new analytical procedures need to be developed (or existing ones modified). These include the following: estimation of annual flood, annual runoff volume, or annual low flow, with a T-year return period; generation of synthetic runoff sequences by time series models, to estimate frequencies of occurrence of extremes; intensity-duration-frequency curves for rainfall; regionalization, of any kind; rainfall-runoff models that are calibrated using past records.

It should be kept in mind that quite often one finds that the regions that suffer the greatest human impacts are also the ones where measurement networks are least developed. This is true of many developing country regions where lack of hydrometric data, coupled with the effects of climatic and land use changes, have led to depletion of water resources and ecosystem degradation.

IAHS PUB Initiative

The IAHS Decade on Predictions in Ungauged Basins (PUB) is an initiative of the International Association of Hydrological Sciences (IAHS). It is aimed at formulating and implementing appropriate science programmes to engage and energise the scientific community, in a coordinated manner, towards achieving major advances in the capacity to make reliable predictions in ungauged basins.

PUB Community Objectives

The science programmes to be implemented within PUB will have the following five broad community objectives:

1. Advance our ability to predict with confidence the fluxes of water and associated constituents from ungauged basins, evaluated with data from selected basins in different biomes or hydro-climatic regions, including quantification of the uncertainty in these predictions in a routine manner;
2. Advance the technological capability around the world to make predictions in ungauged basins, firmly based on local knowledge of the climatic and landscape controls on hydrological processes, along with access to the latest data sources, and through these means to constrain the uncertainty in hydrologic predictions;
3. Increase the awareness of the value of data, especially the gauging of hydrologic variables, for the management of water resources and water quality around the world, and demonstrate the need for targeted gauging of currently inadequate or nonexistent data sources by quantifying the links between data and predictive uncertainty;
4. Advance the scientific foundations of the science of hydrology, including the understanding of the climatic and landscape controls on the natural variability of hydrologic processes, and on the resulting uncertainty of predictions, and the impacts of human-induced alterations to climate and landscapes.
5. Actively promote capacity building activities in the development of appropriate scientific knowledge and technology to areas and communities where it is needed.

Nature of Predictions

Prediction is concerned with estimating the frequency of occurrence, in the future, of events of any given magnitude, without reference to the times at which they would occur. Forecasting is concerned with what will be happening at a stated point of time in the future, such as discharge tomorrow, or runoff in the coming month. In PUB, we are concerned with **both** *prediction and forecasting*.

Definition of "Predictions in Ungauged Basins"

PUB is defined as the prediction or forecasting of the hydrologic response (e.g., streamflows, sediments, nutrients etc) of ungauged or poorly gauged basins, and its associated uncertainty, using climatic inputs (observed, forecast or otherwise specified), soils, vegetation, and topography, including any predicted or expected future climatic or land use changes, but without the benefit of past observations of the particular hydrologic response that is being predicted, i.e., with no possibility or allowance for *local tuning or calibration*.

But what do we want to predict?

The hydrologic response we want to predict depends on the nature and scale of the problem. PUB recognizes that water quantity and water quality problems have different implications for management and the emphasis in hydrologic predictions may be different. Examples of water quantity predictions include floods of a given return period, mean annual water yield, reliability of water supply, crop yields, and irrigation scheduling. Examples of water quality predictions include conservative and non-conservative constituents in streamflow, such as salinity, nutrients, and heavy metals. Water quality predictions require prior knowledge of water sources and pathways within the basins and cannot be performed adequately without first addressing issues related to water quantity and the distribution of flow pathways and residence times. Consequently within PUB, predictions of hydrologic response in ungauged basins will be initially focused more heavily on water quantity, yet recognising that knowledge of the flow partitions (pathways) is critical for water quality predictions.

In general, the required hydrological response can be a continuous time series of the quantity of interest, e.g., storm hydrograph, hydrograph of water sources components, hydrologic state variables etc. (for forecasting), or statistical measures of its variability in space or time, e.g., mean, variance, annual totals, extremes (floods or droughts) of a given probability of exceedance etc. (for prediction).

It should be noted that in the past environmental and water resources management have been narrowly focused on one or a few aspects of the natural environment, manipulating them for human use or bringing them under control to benefit human habitation. This has spectacularly advanced human health and welfare, but society has since come to expect more sophisticated, multi-dimensional solutions to its needs and desires. For example, the simplification or destruction of aquatic and riparian ecosystems that accompanied many engineering activities is now generally considered undesirable and in need of reversal (Dunne, 1998). Therefore, predictions that will be sought in the future are likely to be much more complex, multi-disciplinary and holistic, requiring much more finesse and flexibility than ever before.

Suite of Current Approaches to PUB

<and limitations associated with these methodologies>

1. *Observe on site*: <expensive, cutbacks to gauging, yet is very important to rationalize and maintain>. Note: PUB is not a substitute for gauging!
2. *Extrapolate from gauged basins* (regionalisation): <heterogeneity of land surface, and thus lack of transferability, lack of availability of similar gauged basins nearby>
3. *Observe by remote sensing*: TRMM, GPM, IGOS-Water, NOAA, JERS, SAR, GPS, laser altimeter (TOPEX/POSEIDON): <coarse resolution, difficulty with hydrologic interpretation of measurements, lack of ground truth data>
4. *Hydrologic model simulation*: <unavailable climatic inputs, landscape attributes, land use change, water use and regulation data, lack of basin data for validation, parameter identifiability, model transferability>
5. *Integrated meteorological and hydrological model*: <accuracy, data availability on landscape properties, parameter identifiability>

PUB Targeted Research: Focus on Reduction of Predictive Uncertainty

A number of approaches are currently available for predictions of basin responses. The most obvious of these is measuring on site, which by definition is precluded in ungauged basins. Methods appropriate for ungauged basins include extrapolation of response information from gauged to ungauged basins, measurements by remote sensing (radar, satellites etc.), application of process based hydrological models where the climate inputs are specified or are measured, and application of combined meteorological-hydrological models without the need to specify the climate inputs. Many of the currently available prediction methods are often mistaken to be reliably precise, and used uncritically, by those looking for a convenient, objective way of making decisions about environmental management. The capabilities of these models or methods are frequently overstated, or at least not critiqued, by their developers and proponents, especially in the light of human-induced alterations to the climate and the land surface.

Whichever of the above approaches is used, the underlying model or estimation method that one uses for predictions in ungauged basins must be 1) inferred from observed data in gauged basins, 2) obtained from process understanding and descriptions obtained through laboratory studies, e.g., Darcy's law of porous media flow, or field experiments (plot scale, hillslope scale, small catchment scale, meso-scale), 3) obtained through application of fundamental theories, which must still be conditioned by observations. This is also the case with the remote sensing approach – the model that connects the remotely sensed product to the hydrological quantity of interest also must be inferred or developed in gauged/ground-truthed sites, before being extrapolated to ungauged sites. Therefore, one way or the other, perhaps to varying degrees, predictions in ungauged basins must involve extrapolation of some kind from what is observed or inferred at one basin to a time in the future at the same location, or to another basin at a different location (ungauged basin).

Each of the approaches presented above has a number of limitations when it comes to predictions in ungauged basins. These pertain to the inadequacies of the models or estimation methods themselves, due to the inadequate representations of critical processes governing the basin response of interest, and the incomplete specification of information relating to the properties of the basin of interest and the climatic inputs. A key difficulty is that the predictions by the model cannot be conditioned or validated by observations in the ungauged basin of interest, and that information, knowledge and understanding must be extrapolated from gauged to ungauged basins. Consequently, predictions in ungauged basins cannot be evaluated or verified with confidence, and are inherently uncertain.

The core research programmes within PUB are therefore geared towards:

1) evaluating the performance of existing prediction methods that could be used in ungauged basins, through comparative analysis of a full range of methods and detailed investigations of the processes governing the quantity of interest, identifying, where appropriate, the inadequacies of the current methods so as to provide signposts for new scientific developments;

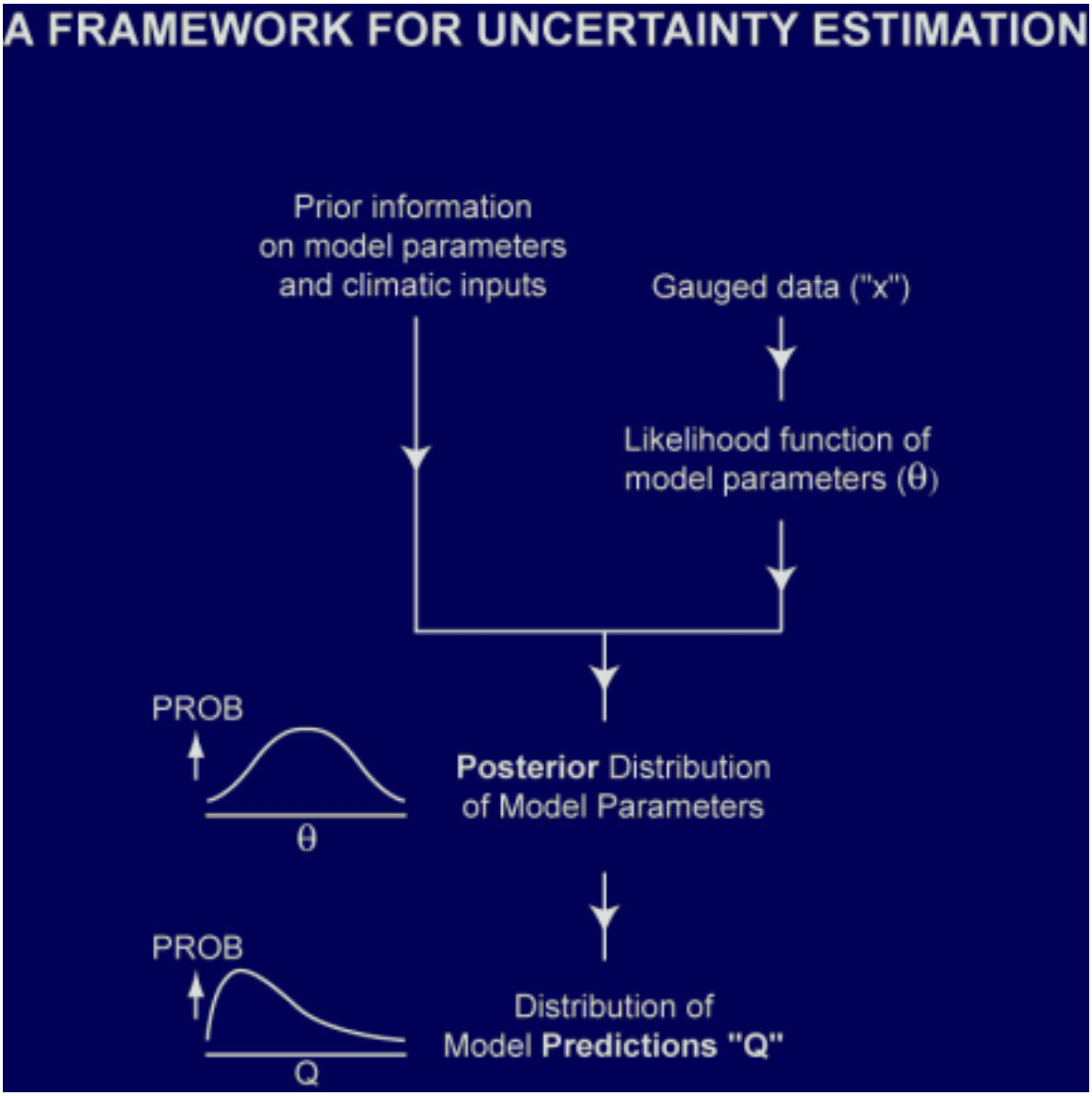
2) demonstrating the value of data, knowledge and process understanding for improved hydrologic predictions, thus providing guidance for data collection programmes, remote sensing developments, and new ground–based instrumentation and field experiments, and for using widely available digital data sets; and

3) understanding the hydrologic functioning, i.e., dominant processes, of basins at different time/space scales, and how these vary across scales in the different hydroclimatic regions of the world, how the

hydrologic functioning constrains or controls ecological functioning, atmospheric exchanges and fluxes of water, sediments and nutrients to the oceans etc., and exploring how we can incorporate this new knowledge within appropriate models for future predictions.

Common amongst all three programmes will be a sharp focus on realistic estimation and eventual reduction of the level of **"predictive uncertainty"**. Robust measures of predictive uncertainty will be adopted as the criteria of success of PUB, which is a key point of departure in comparison to previous IAHS-sponsored and other national and international hydrological initiatives. Through its sharp focus on predictive uncertainty, PUB will therefore adopt and foster a self-critical approach to hydrologic predictions by addressing what is not known or not understood, and emphasizing the need for empirical exploration and explicit attempts to generate, falsify and validate new ideas and new forms of knowledge.

Also, the focus on predictive uncertainty will enable hydrologists to go beyond quick fixes, to search for new and innovative solution approaches and paradigm shifts, and to seek knowledge and understanding of natural processes beyond the immediate problem-solving needs of construction, environmental management or regulation.



The Bayesian approach to estimating predictive uncertainty is only one of many alternative approaches that will be explored during PUB. Other methods include Monte Carlo procedures,

application of fuzzy logic, the use informational entropy, and the generalised likelihood uncertainty estimator (GLUE).

PUB Enabling Research on Heterogeneity and Uncertainty

Keeping in mind the key core objectives outlined above, and the sharp focus on "predictive uncertainty", the proposed PUB Science Plan will include a suite of "enabling" research programmes, integrating across various hydrologic sub-disciplines, which are articulated through the following six science questions:

Question 1: What are the key gaps in our knowledge that limit our capacity to generate reliable predictions in ungauged catchments?

In order to make predictions of any specified response of a river basin, a general hydrological prediction system must contain three components:

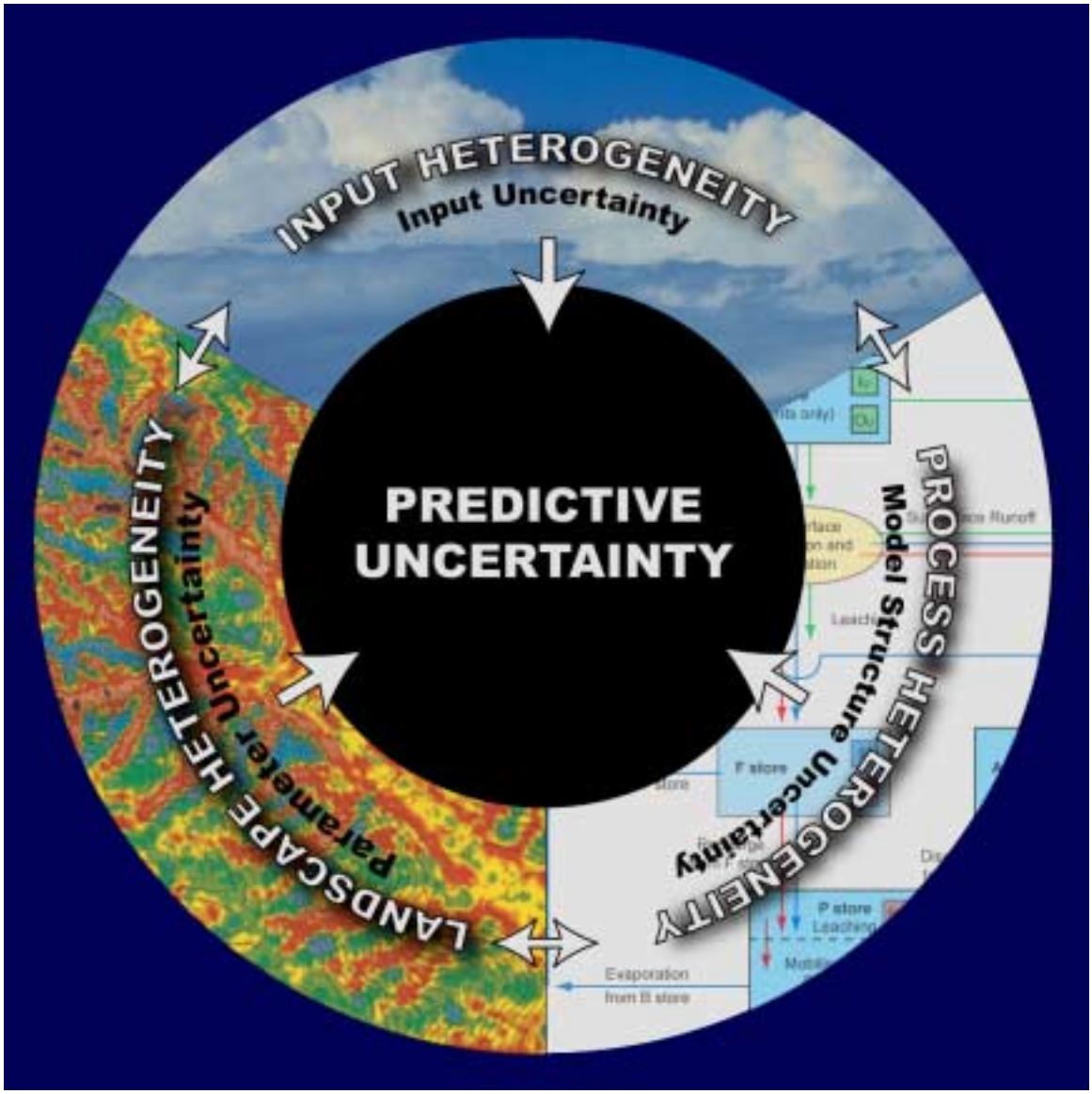
- a model: model or prediction method that either implicitly or explicitly incorporates the combination of processes that lead to the quantity of interest, at the required space and time scales;
- climatic inputs: appropriate meteorological inputs (if needed by the model) that drive the basin response; and
- parameters: a set of parameters that represent those landscape properties that govern the basin response of interest.

Each of the components of the prediction system, namely, model, climatic inputs and parameters is either not known at all, or at best known imperfectly, especially in ungauged basins. The sources of the lack of knowledge or inadequate knowledge, in each case, can be traced back to the multi-scale heterogeneity of climatic inputs and the landscape properties, and the resulting multi-scale heterogeneity of the hydrological processes that arise from the nonlinear interactions between the climatic inputs and the landscape properties.

Set against these enormous heterogeneities, available measurements relating to each of these are extremely sparse and patchy, this problem being most acute in the case of hydrologic processes as they are the least monitored quantities in basins, except in some highly focused field experiments. Therefore the central themes of PUB will be evaluating the consequence of inadequate knowledge, understanding or data, with respect to the uncertainty of predictions. In the context of the general prediction system and the tremendous heterogeneity of nature, one can therefore think of three kinds of uncertainties: 1) uncertainty in process descriptions in the adopted model, due to the "uncertain mapping of landscape space to model space" (model structure uncertainty), 2) uncertainty in the climatic inputs (input uncertainty), and 3) uncertainty in the model parameters (parameter uncertainty). Hence PUB will include scientific programmes to make inferences about climatic inputs, parameters and model structures from available but inadequate data and process knowledge, at the basin of interest and from other similar basins, with a robust measure of the uncertainties involved and their impacts on the uncertainty of predictions.

Definition of “Predictive Uncertainty”

Uncertainty of hydrological predictions occurs at two different levels. The inherent uncertainty associated with any given model is caused by uncertainties in the estimated parameter values (e.g. data sparsity, measurements errors) and in the climatic inputs. Given the model, these uncertainties propagate through the model and contribute to the uncertainty in the final result. The larger the number of parameters that have to be estimated and the more uncertain their estimates, the higher will be the resulting predictive uncertainty. The second kind of uncertainty arises from the imperfectness in the model that is used to make predictions in a specific basin. If many different ‘legitimate’ models give widely different predictions for the same catchment, the model structure uncertainty must be high. Since it is unclear if any of the available models can make accurate predictions in an ungauged basin, model structure uncertainty can only be assessed by comparison with measured data in the catchment of interest, or in similar catchments in the same hydroclimatic zone.



Enabling Research: Investigate the connection between heterogeneity and predictive uncertainty

- Develop a hydrological prediction system that is capable of routinely assessing the errors or uncertainty in model predictions, and quantifying the different sources of the uncertainty – parameter estimates, climatic inputs and model structure
- Develop science programmes to make inferences about climatic inputs, parameters and model structures from the available but inadequate data and knowledge about processes, at the basin of interest and from other similar basins, with a measure of the uncertainties involved.
- Develop systematic programmes to collect more data and carry out highly focused field experiments in different hydroclimatic zones, to advance our current theories for dealing with incomplete data, to improve process descriptions, and to make useful inferences from data from existing gauging networks.
- Develop methodologies to constrain predictive uncertainties at ungauged sites by making the best use of the information available from other sites, and measurement programs implemented at the site of interest.
- Investigate the links between landscape heterogeneity and nonlinearity, parameter identifiability, and predictability, including limits to predictions.

- Explore alternative or non-traditional forms of predictions, where the nature of the problem or data availability precludes traditional forms of predictions, as in the case of episodic occurrences of pesticide export, blue-green algae in surface waters, gully erosion and sediment export.

Question 2: What are the information requirements to reduce predictive uncertainty in the future?

The response of a basin depends on the interaction between the climate inputs and landscape features, such as soils, vegetation, topography, land use etc. Basin scale predictions therefore require knowledge about the distribution of soils, plants, and topography to define the spatial and temporal patterns of soil moisture storage, its availability for evapotranspiration, and its control of runoff generation and transport processes, including the rate at which various chemical constituents are mobilised and transported. Depending on the predictive method (e.g., model), and the spatial and temporal scales of the application, we need to convert available information on climatic inputs and landscape features into model inputs and parameter values, and uncertainty arises during each of these conversions.

Enabling Research: Investigate heterogeneity of landscape properties and climatic inputs for estimation of model inputs and parameters

- Carry out analysis of raingauge data and satellite and/or radar data to characterise space-time heterogeneities of rainfall fields, their error structures and the resulting uncertainties of precipitation inputs into models.
- Investigate empirical ENSO teleconnections, and observations of multi-decadal variability of climatic inputs, with the use of stochastic models capable of incorporating these inherent nonstationarities.
- Advance our capability to make predictions of the effects of long-term (multi-annual and multi-decadal) climatic variability and change on hydrological responses and associated uncertainties.
- Carry out research to estimate parameter values and measures of the associated uncertainties, and to constrain these through the use of surrogate information, terrain attributes and pedotransfer functions.
- Carry out objective and multi-scale inter-comparisons of quantitative and descriptive information (i.e. hard and soft data) to overcome their mutual scale incompatibilities and inherent error structures.
- Explore efficient characterizations of the multi-scale heterogeneity of landscape properties and climatic inputs and the effects of such sub-grid heterogeneities on model parameterizations.
- Carry out research into the inter-connections between climate, soils and vegetation arising out of co-evolution of these characteristics, their impacts on predictive uncertainties, and parsimony of parameter estimation methods.
- Explore, through models, the key additional data that may be required to constrain predictive uncertainty, as a motivation for new measurement techniques, data collection programmes, and field experiments, for the estimation of parameter values and internal state variables.

Question 3: What experimentation is needed to underpin the new knowledge required?

To reliably predict any hydrologic response or quantity of interest, we need to have sufficient understanding of the combination of hydrologic processes that generate it at the scales of interest. These hydrologic processes arise out of dynamic interactions between atmosphere and the land surface and involve nonlinear transformations in time and space, due to the variety of flow pathways that water follows, and the physical and biogeochemical transformations that occur along these pathways. Some of the major parametric and model structure uncertainties of process-based hydrologic models can be reduced with carefully designed field experiments at a range of time and space scales.

Enabling Research: Process studies and meso-scale field experiments worldwide for theory development and model improvement

- Carry out new multi-scale field experiments in meso-scale basins that can generate previously unobserved space-time variabilities of hydrological processes. Examples include measurement of internal variables such as groundwater levels, soil moisture, saturated areas and tracer movements (isotopes, geochemistry) for identification of flow pathways.
- Carry out observations of large-scale processes (continental scale floods, the impact of regional drought, the discharge of groundwater in a stream network, down-valley advection and diffusion of sediment waves), and develop new modes of observation to stimulate new questions for analysis at smaller scales (Dunne, 1998).
- Expand the use of hillslope scale and meso-scale field experiments and process studies in a variety of hydroclimatic regions to improve process understanding, and to develop scale-dependent process conceptualisations and improved model structures.
- Carry out systematic monitoring and observations of large river basins in the aftermath of major flood disasters, earthquakes and volcanic activities, and major engineering projects such as flow diversions, building of dams, irrigation schemes and large-scale deforestation activities etc.
- Carry out systematic observations of hydrologic processes over a large range of time and space scales, in order to explore change of dominant processes with a change of spatial scale, or with extrapolation to extreme events, and to understand the critical role of climate and landscape factors in these transformations.

Question 4: How can we employ new observational technologies in improved predictive methods?

PUB is deeply concerned with helping to make predictions in remote, data-poor regions, and to complement existing ground-based data and gauging. Remote sensing and other related modern technologies are likely to become a rich source of data that will be extremely valuable for PUB. Examples include use of laser altimeters for accurate measurements of topography, distributions of atmospheric water budget with passive microwave sensors, ground level radar for precipitation fields, global measurements of radiation and surface temperature, and regular measurements of snow cover, plant cover and surface soil moisture.

Current remote sensing data sources are still too coarse to reflect the scale of the dynamics of runoff, soil erosion etc., yet are too crucial to our ability to observe large-scale processes such as floodplain inundation and the generation of massive sediment pulses from regional scale intense rainfall. Therefore PUB will actively foster research geared towards increasing hydrologists' capability to utilise available remote sensing products in a routine manner, and will provide advice and inputs towards the development of hydrologically relevant instrumentation in future remote sensing missions.

Satellite-based remote sensing yields a pixel-averaged view of the earth's surface from the top of the atmosphere, and is better at providing a spatial coverage than the kind of temporal coverage valued by small-scale hydrology. PUB will therefore strive to combine remote sensing products with more thorough and creative fieldwork, in order to investigate what is being represented, and to articulate the specific data types and resolutions needed to resolve processes at smaller scales.

Enabling Research: Advancing the use and development of remote sensing and other novel observational technologies

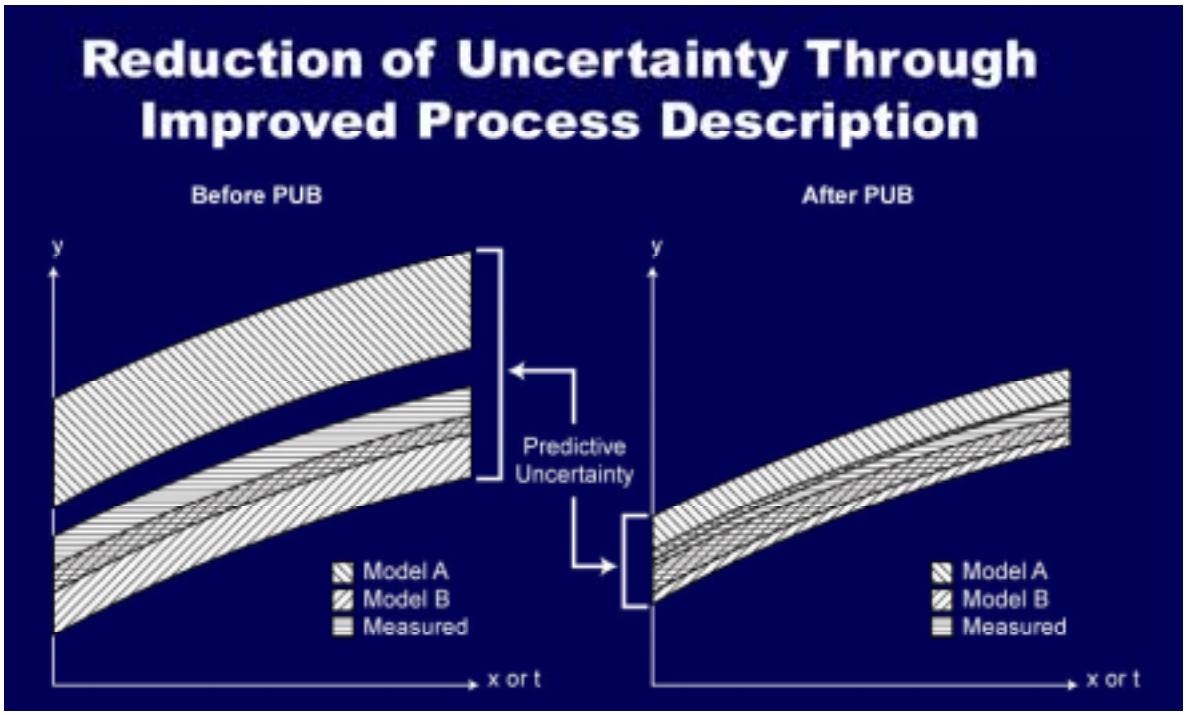
- Assess and accordingly extend the use of existing remotely sensed landscape properties (soils, vegetation cover, topography), and meteo-climatic surrogates (radar, IR, visible and microwave data).
- Advance mathematical techniques to characterize such data in an efficient manner and for downscaling these variables to basin scale to satisfy the data requirements of hydrological models.

- Promote research to enhance our ability to measure precipitation, soil moisture, saturation area dynamics, surface water stages, floodplain inundation, runoff, and evapotranspiration at the scales at which predictions are required;
- Develop new data processing methodologies, especially for remote sensing data in combination with sparse ground-based networks, to deal with the wide range of space-time scales, measurements at different scales and of different dimensionalities (e.g. 1-D time series, 2-D satellite images, 3-D radar data, etc.) and their assimilation.
- Promote the development and implementation of new observational technology (ground-based field experiments, tracer techniques, as well as remote sensing) for making space-time observations for hydrologic purposes, guided by theoretical and process-based considerations.

Question 5: How can we improve the hydrological process descriptions that address key knowledge elements that can reduce uncertainty?

Improvements in process descriptions relating to the predictions of the quantities of interest can be achieved in a number of ways. Process studies and multi-scale field experiments can give insights into processes and mechanisms, and how these change with scale. Measurements of internal fluxes and state variables can be used to validate and improve process descriptions in models. Results from a variety of field experiments in different hydroclimatic settings can help to form and improve perceptual models of the basin response, which can be the basis of improved numerical models. Advances in modeling capability and process descriptions can also be made through developing new model frameworks that can naturally accommodate the heterogeneities of landscape features and climate inputs.

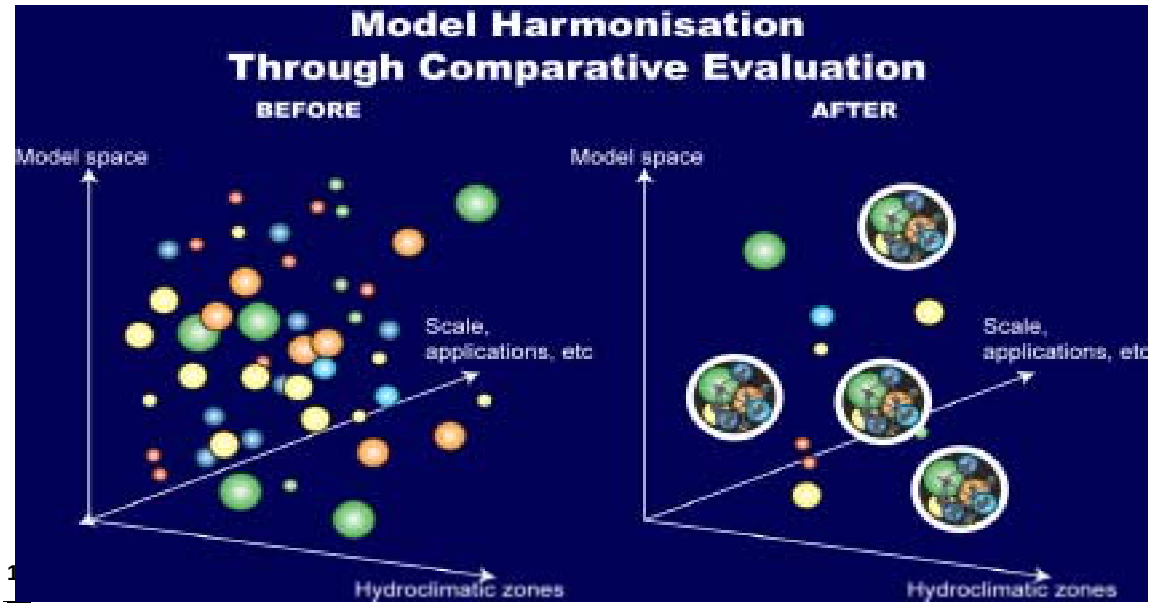
One important challenge for basin scales hydrologic predictions is to represent processes, material properties, and boundary conditions that are characterised by small-scale spatial and temporal variations that cannot be resolved with foreseeable measurements and computational resources. Such processes and properties have to be represented through “parameterizations”, which express the averaged behaviour of unresolvable effects and the effects of the various nonlinear interactions on process rates (average rate of evapotranspiration, erosion rates etc.). The requirement for intelligent and thorough parameterization of the effects of small-scale process heterogeneities thus provides a clear focus for integration of theoretical and field investigations under PUB.



Even with the availability of detailed information on processes and flow pathways, obtained from sophisticated field experiments, the reality is that due to the limited data available in ungauged basins, many models may be found to be inadequate for the purpose, unless and until they are conditioned with data. Therefore PUB will have an active programme of applying a variety of models to selected basins in different hydroclimatic zones around the world, and learning from a comparative evaluation of model performance, conducted within the uncertainty framework. This is with the view to identifying potential areas for making improvements to model structures and process descriptions, and to an eventual harmonization of models and modeling approaches that will be applicable to specific hydroclimatic regions at specific time and space scales.

Enabling Research: Advancing process descriptions through field experiments and comparative evaluation of models in selected basins in a variety of environments

- Develop modelling frameworks for the development of a new generation of models that can account for multi-scale heterogeneities, and parameterisations of the effects of sub-grid heterogeneity
- Improve our understanding and description of the interactions between rainfall-runoff processes, and the chemical and biological processes, at all time and space scale, crucial for water quality predictions;
- Identify candidate PUB basins, representing a wide range of hydroclimatic zones; make data available to the wider research community for the purposes of PUB-related research activities, in particular, for comparative evaluation of model performances and model diagnostic studies.
- Evaluate a variety of existing and new models, within a predictive uncertainty framework, with gauged data in selected PUB basins around the world, through learning by conditioning with the gauged data and exploration of the connections between model performance and description of dominant processes.
- Classify model performances in terms of time and space scales, climate, data requirements and type of application, and explore reasons for the model performances in terms of hydrological insights and climate-soil-vegetation-topography controls.
- Review and compare different models and modelling approaches to assess gaps in knowledge and model capability, and to come up with generic model conceptualisations appropriate for different problems and time and space scales (i.e., modelling toolkits), using elements that are common between different types of models, in this way helping to harmonise the approaches that are currently available and being used.



Question 6: How can we maximise the scientific value of available data in generating improved predictions?

The approaches we have for predictions in ungauged basins involve the use of existing data or surrogate data at the same or neighbouring sites. Existing data in gauged basins can be extrapolated to ungauged basins through the use of models that are based on process understanding gained previously, or empirical relationships developed between the quantity of interest and landscape attributes and climatic inputs.

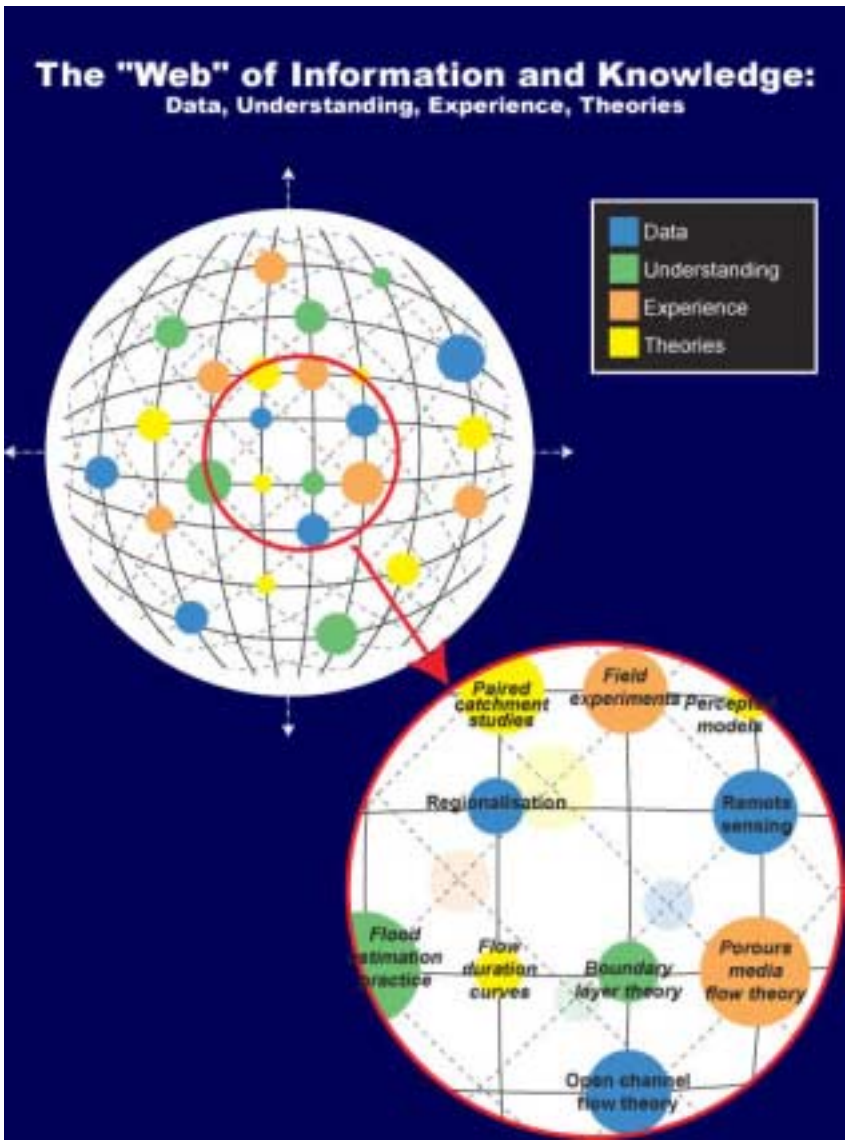
A number of approaches to adding value to the available data will be explored as part of PUB. These include analyzing available gauged data and interpreting the underlying patterns, such as observed differences between basins in the same region and between regions, in terms of the underlying climate-soil-vegetation controls. Top-down approaches attempt to decipher the physical causes underlying observed patterns of variability, and can assist towards developing parsimonious models of basin responses.

Enabling Research: Interpretation of existing data through models of climate-soil-vegetation interactions, and assimilation of gauged and/or remotely sensed data through dynamic models

- Improve our understanding of the currently observed variability over a wide range of time and space scales of rainfall and runoff processes (within and between catchments), including extremes, their interpretation in terms of the underlying climate-soil-vegetation-topography interactions.
- A quantitative classification of basins and basin responses in different hydroclimatic regions of the world based on detailed understanding of climate-soil-vegetation-topographic controls on observed variability of basin responses
- Develop mathematical techniques for the characterisation of space-time variability at multiple scales: fractal structures and multi-fractal fields, wavelets analysis, nonlinear dynamics.
- Explore and enhance the use of traditional (e.g., gauged streamflows), and new data resources, i.e., remotely sensed data on soil moisture, river water levels etc. to constrain predictive uncertainty through data assimilation exercises, in combination with existing models and model structures and with improved ones in the future.
- Pursue top-down approaches to deciphering parsimonious model structures, and interpreting patterns in observed data through explorations of climate-soil-vegetation-topographic interactions.
- Explore methods to decrease predictive uncertainty through a merging of data, theory and improved process understandings from different disciplines (e.g. the use of chemical isotopes for hydrograph separation, and identification of flow pathways).
- Develop a theoretical framework for the evaluation of patterns within or underlying observations of basin responses (e.g., data mining), and the discovery of new laws governing hydrologic response, by interpretation of these patterns through tests of hypotheses involving the use of simple models (ie., caricatures) of basin response.
- Develop new uncertainty criteria to detect, evaluate and interpret patterns caused by nonlinear and/or threshold processes, including new uncertainty bounds required to deal with the resulting pattern dynamics.

Summary of PUB Enabling Research Programme

Through the concerted activities focused on the six enabling research questions presented above, PUB will help generate a “web” of new information and different forms of knowledge, including but not limited to new data, understanding, experience and theories, which will all be utilised collectively towards the reduction of predictive uncertainty. This research will be coordinated with other national and international programs, including the various IAHS International Commissions.



PUB IMPLEMENTATION PLAN

The PUB Implementation plan outlined below is underpinned by a number of guiding principles, which arise from the fundamental nature of the IAHS as an organisation, and the nature and present status of the science itself. Firstly, the IAHS is an international association of hydrologists, but is not a funding body or even a research organization; therefore it can only mobilise and lead the hydrologic community, but cannot produce the research outcomes. Secondly, hydrology as a combination of natural science, earth science, empirical science and applied science, has placed on itself demands from each of these affiliations, and PUB must accommodate the activities of hydrologists in each of these fields of specialisation. Therefore, we have chosen PUB to be a grassroots level activity or mass movement, accommodative of the diverse interests of hydrologists worldwide, with the IAHS and the SSG playing coordinating and catalytic roles in mobilising the community towards achieving the PUB research targets.

Plurality of Applications

PUB is essentially a scientific programme, yet PUB will concern itself with phenomena that are of direct interest to society. This will enable hydrologists to gain support for their activities amongst the wider community through their functioning as engaged members of society. From this philosophical perspective,

PUB recognises that hydrologic predictions will be required for a variety of water-related environmental applications:

- flood estimation
- climate variability and droughts
- erosion and sedimentation
- snow and ice and snowmelt
- nutrients and eutrophication of receiving waters
- land use and salinity

While hydrology is fundamental to all of these applications, the focus in each application is on different hydrological processes. For example, a prediction method for flood estimation may emphasise different processes compared to a prediction method for nutrients. Hence a comparison of the approaches used for different applications has the potential to yield important insights into the various hydrological processes and can lead to significant improvements in predictive capability in all applications.

Plurality of Prediction Methods

PUB recognises that there are a variety of potential approaches being used already, and potentially applicable in the future, for predictions in ungauged basins:

- extrapolate from gauged basins (regionalisation)
- observe by remote sensing
- hydrological model simulation
- integrated meteorological and hydrological model

While each method has its own limitations, interestingly each of them incorporates different information and different forms of knowledge, and each has some advantage over the other. Therefore, while each method can be improved by going back to the underlying theory and process descriptions and data sources, PUB takes the view that a combination of the different approaches through cross-fertilisation of data, knowledge and process descriptions can yield a much faster reduction of predictive uncertainty.

Plurality of Hydrological Models

PUB recognises that since we do not have the ability to condition models with data on site (i.e., being ungauged basins), a plurality of models and modelling approaches may be valid for the same basin and application:

- empirical models
- stochastic models
- distributed models
- lumped models
- soil-vegetation-atmosphere-transfer (SVAT) models

PUB takes the positive attitude that one can learn a lot through a comparative evaluation of the performances of a variety of models when simultaneously applied to selected “gauged” basins. The cross-fertilisation of ideas and insights into process descriptions gained from evaluation of model performances will contribute towards a harmonisation of the models and modelling approaches and will lead to a faster reduction of predictive uncertainty.

Plurality of Hydroclimatic Zones

PUB recognises that the hydrological responses of basins are highly heterogeneous across the major hydroclimatic zones of the globe. Models and prediction methods that are applicable, for any specific estimation problem, in humid regions of the world may not be applicable in semi-arid regions.

- arid to semi-arid regions
- humid regions
- tropical
- cold regions
- Mediterranean regions
- karstic regions
- monsoon Asia

Therefore, PUB takes the view that a plurality of approaches must be pursued to account for the major differences in hydrologic behaviour between these hydroclimatic regions. Yet, PUB has adopted the positive attitude that a comparison of existing models and prediction methods in basins selected in different hydroclimatic regions of the world can lead to improvement of process descriptions in all models for all basins, and a harmonisation of modelling approaches used worldwide.

Plurality of Enabling Research Programmes

From a general prediction system perspective, all prediction approaches have common elements, even if they have been developed with different applications in mind. As described before in detail, there is a lot of scope for bringing to bear different forms of knowledge, understanding and data towards making improvements in predictions in ungauged basins. PUB will therefore support a number of enabling research programmes to advance designed to advance the predictive capability of existing methods:

- investigation of the connection between heterogeneity and predictive uncertainty
- investigation of heterogeneity of landscape properties and climatic inputs for estimation of model inputs and parameter values
- process studies and meso-scale field experiments worldwide for theory development and model improvement
- the use and development of remote sensing and other novel observational technologies
- improvement of process descriptions through field experiments and comparative evaluation of models in selected basins in a variety of environments
- interpretation of existing data through models of climate-soil-vegetation interactions, and assimilation of gauged and/or remotely sensed data through dynamic models
- investigation of the impacts of hydro-climatological variability and change and land use change

Again, PUB recognises that implementation of a plurality of such research programmes will be needed to make substantial improvements to model capability and consequent reductions of predictive uncertainty.

Organising Principle of PUB: “Design the Process, Not the Product”

Plurality of Applications, Approaches, Models, Basins, Enabling Research Programmes Towards Single Common Objective, with Single-Minded Focus and Singular Belief

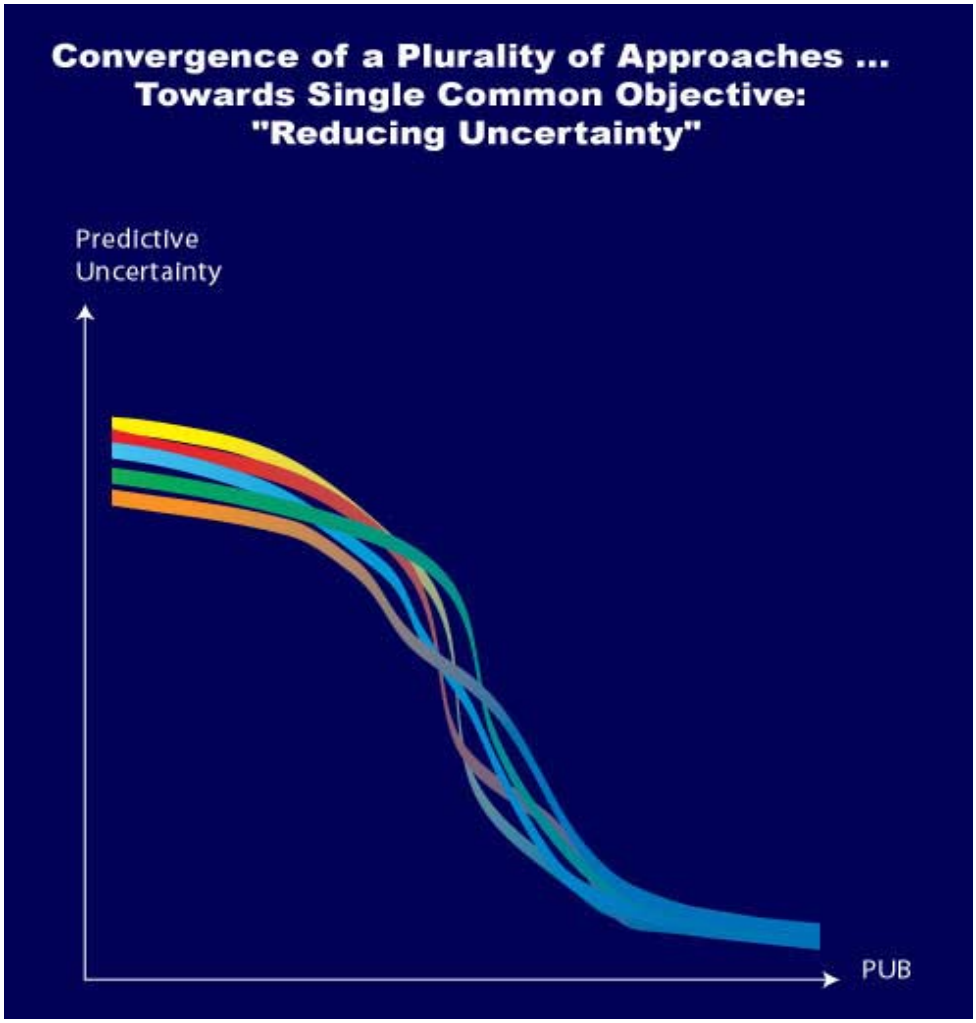
In summary, PUB recognises the variety of contexts within which predictions are required for river basin management (scales, applications, hydroclimatic zones). Similarly, PUB recognises the variety of models or predictive methods that may be applied. Regardless of the context, and the methods used, PUB has identified a variety of enabling research programmes to make improvements to our current predictive capability. In every one of these cases, PUB has chosen to adopt and support a plurality of approaches, as opposed to an imposed artificial uniformity. This is consistent with the fact that PUB is not a funded

research project, and should be seen as a grass-roots level, global mass movement, and therefore it will work most effectively if it builds synergistically on ongoing activities.

In contrast to the encouragement of a plurality of applications, prediction methods, models, hydroclimatic regions, and enabling research programmes, PUB will have the exciting feature that it will have:

- a single minded focus on “predictive uncertainty”,
- a single common objective of “reduction of predictive uncertainty”, and
- a singular belief in the adoption of a plurality of prediction approaches and model improvement strategies.

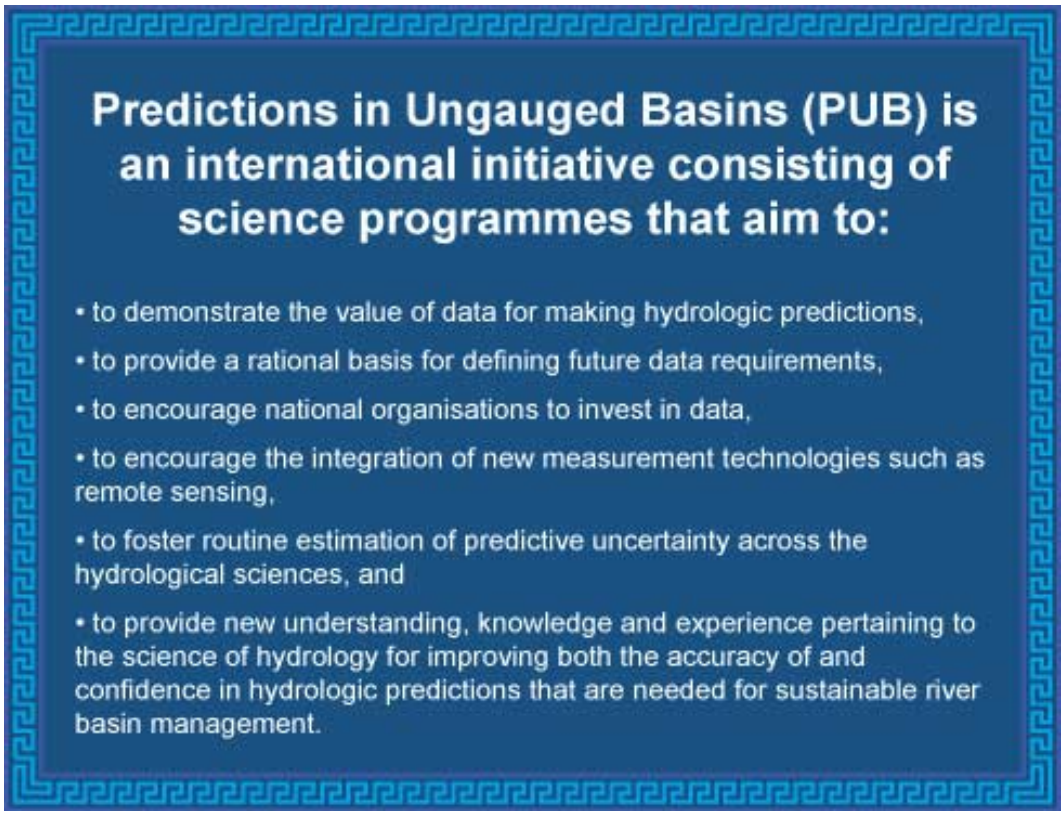
In this way, PUB will become the catalyst for a harmonisation of the variety of existing approaches for predictions in ungauged basins, incorporating both substantial diversity and demonstrable coherence, thus paving the way for a unification and revitalization of the science of hydrology. A well-defined, coherent, and skilfully articulated and publicized science agenda devoted to PUB is likely to recapture the imagination of policy makers and water managers, since they can clearly see the social benefits, or at least the public interest, in the scientific objectives being proposed for PUB.



STRUCTURE OF PUB ORGANISATION AND ACTIVITIES

The proposed structure for PUB research activities has been aimed at fostering a flexible, self-organising framework which …

- is inclusive of the diverse range of research interests within the hydrological scientific community, and a similarly wide range of applications;
- amenable to the adoption of uncertainty estimation on a routine basis;
- enables comparability of the performance of a plurality of approaches with regard to specific objectives;
- encourages the integration of different areas of expertise towards specific common objectives;
- emphasizes the merging or assimilation of theoretical advances, process understanding, new data technologies and evaluation of model performances in different contexts (scales, applications, hydro-climatic zones etc.) towards the reduction of predictive uncertainty; and
- through insistence of these fundamental organizing principles in the organization of the various science programmes within PUB, helps to unify and harmonise the hydrological community for rapid advances of the science and its societal relevance.



Affiliation with PUB: Networks of PUB People

The PUB research programme will be undertaken by scientists from around the world with a demonstrated commitment to the principles and objectives of PUB, as outlined in this Science and Implementation Plan. In particular, commitment to uncertainty estimation, comparability of performance of a plurality of approaches, and the assimilation of theory, data and process understanding towards uncertainty reduction will need to be demonstrated.

There are three ways of being associated with PUB activities: 1) create or join what will be called **PUB Working Groups** (PUB WGs) which will be affiliated to PUB, or alternatively, 2) form projects or project teams that will be certified as **PUB Individual Projects** (PUB IPs). 3) PUB will also develop links with groups carrying out research activities that address the PUB Enabling Research questions, such as data assimilation, remote sensing, process studies and meso-scale experiments (CHASM, LOCAR etc.), theoretical hydrology (e.g., IAHS Working Group on Theoretical and Observational Hydrology), and

model inter-comparison studies (MOPEX, DMIP etc). Particular mention is made of the various IAHS International Commissions, who are expected to play key roles in carrying out these activities.

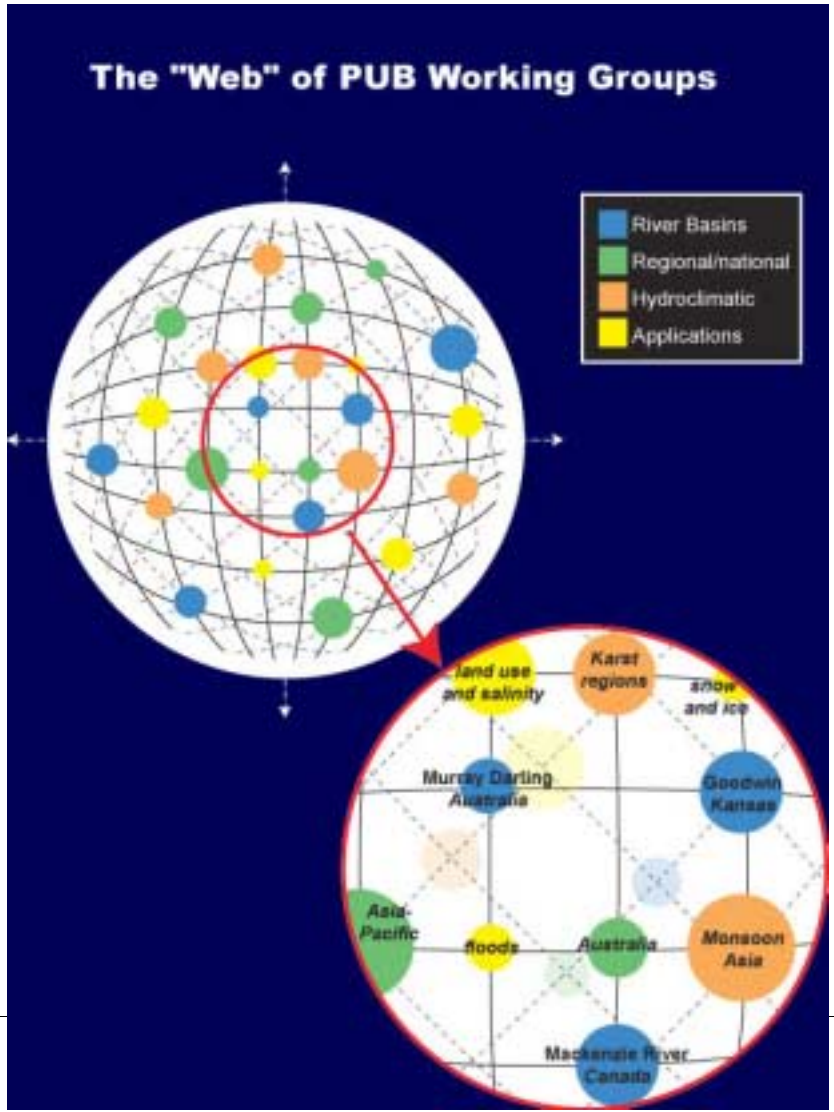
Network of PUB Working Groups

PUB will aim to mobilise interested researchers in any area of prediction in ungauged basins to form collaborative groups, called PUB Working Groups, ideally cutting across traditional thematic areas (such as remote sensing, purely field-based approaches, theoretical developments, calibration, model evaluation, etc.), and get these Working Groups to undertake the integrative research required to accomplish PUB core research targets. Indeed, PUB is convinced that a narrow focus on rigid thematic areas (theory, remote sensing, field experiments etc.) is counterproductive for PUB and therefore should be discouraged.

PUB Working Groups will be formed in a self-organized, spontaneous manner, around the world. PUB envisions a number of different types of Working Groups centred on:

- River Basins: Goodwin (Kansas), Mackenzie River (Canada), Murray-Darling (Australia) etc.
- Regional or national: Australia, Asia-Pacific, Mediterranean, Southern African etc
- Hydroclimatic zones: semi-arid, karst regions, monsoon Asia, sub-Saharan Africa, cold regions etc.
- Applications: flood estimation, climate variability and droughts, erosion and sedimentation, snow and ice and snowmelt, nutrients and heavy metals, salinity, eutrophication of receiving waters etc.

The WGs can define their own PUB objectives but will be required to have an emphasis on enabling comparability of a plurality of approaches within each WG, towards well-defined specific common goals, with a singular focus on reducing predictive uncertainty. It is envisaged that multiple WGs may adopt similar objectives in terms of hydrological fluxes/variables; however they may be differentiated according to hydroclimatic regimes, hydrogeological units, land use and/or geographic regions etc. In this way, individual WGs will develop specific insights with respect to predictability within their defined target



areas. However, comparability of predictions between WGs of similar hydrological fluxes/variables under different climate, land surface, and land-use regimes will also be enabled. The emphasis on comparability of PUB activities within and between WGs is aimed at value adding to individual research efforts and helping to harmonise, and reach consensus, in approaches to making hydrological predictions.

Workings of PUB Working Groups – An Example

PUB Working Group 1 - Sediment export estimation in temperate climate zones.

Participants

1. Jacques Hydrologique, University of Florida
2. John Gage, University of Waterloo
3. Jowanna Hydrograph, World Methodological Organisation

Specific objectives:

A. annual sediment export estimates for 3 identified, gauged catchments
B. source fractional contribution estimation for 3 identified catchments

Objective A - Annual sediment export estimates for 3 identified, gauged catchments

Participant 1 adopts a distributed modelling approach
Participant 2 adopts a modified USLE approach using nearby gauged sites for calibration
Participant 3 adopts a regression approach to regionalisation based on nearby catchments

Objective B - source fractional contribution estimation for 3 identified catchments

Participant 1 again adopts a distributed modelling approach
Participant 2 adopts a modified USLE approach on individual subcatchments
Participant 3 adopts a fingerprinting approach based on practical, limited measurements

Working Group Outcomes

Both objectives A and B are addressed from very different methodological approaches. The commonality of the variables of interest in the same specific catchments then enables a limited inter-comparison of the approaches. The first results from this working group provide new insights into the relative merits of the approaches. Importantly, the different approaches have very different information requirements – this enables the identification of a hierarchy of preferred methodologies given practical requirements for prediction in data-sparse or ungauged basins. Additionally, this process can be seen in reverse - this permits the identification of data required, given the accuracy required of the analysis.

To further build on these results, the integration of the range of methodologies may be evaluated – when the different approaches are integrated into a common framework, are the methodologies mutually beneficial? In other words, can uncertainty be reduced through any synergies achieved after integrating these diverse approaches?

Finally, PUB-WG-1 notes that PUB-WG-34 is addressing similar objectives but in the semi-arid environment. The comparability within WGs enables similar comparability between WGs. New insights associated with the performance of different methodologies in different

environments are therefore enabled representing significant value adding to the PUB exercise.

Certification of PUB Working Groups and Individual Projects

Any proposed working group could apply to the SSG for a formal certification as a **PUB Working Group**. Each application will be evaluated on the basis of their meeting the following minimum criteria:

- adoption of uncertainty estimation on a routine basis;
- enabling comparability of performance of a plurality of approaches with regard to specific objectives;
- integration of different areas of expertise towards specific common objectives;
- merging or assimilation of theoretical advances, process understanding, new data technologies and/or evaluation of model performances in different contexts (scales, applications, hydro-climatic zones etc.) all geared towards the reduction of predictive uncertainty.

Once deemed to have satisfied these requirements the Working Group will be officially included in the list of PUB Working Groups (PUB WGs) and their details will be incorporated in the PUB website. All official PUB WGs will be encouraged to share their data and expertise with the rest of the hydrologic community.

Certification of PUB **Individual Projects** will be based on meeting the following two criteria:

- adoption of uncertainty estimation on a routine basis; and
- merging or assimilation of theoretical advances, process understanding, new data technologies and/or evaluation of model performances in different contexts (scales, applications, hydroclimatic zones etc.) geared towards reduction of predictive uncertainty.

Role of and Links to IAHS Commissions

As mentioned before, PUB is committed to encouraging the assimilation of theoretical advances, improved process understanding, new data technologies, and model performance evaluations in different contexts, towards reduction of predictive uncertainty. Within the eleven IAHS International Commissions there exist enormous levels of expertise, accumulated experience and organisational capability, in various sub-fields of hydrology, such as remote sensing, tracer methods, surface and groundwater, climate-soil-vegetation interactions, snow and ice, water quality, erosion and sedimentation, and water resources systems.

PUB will make special efforts to engage and mobilise the expertise and experience available within the IAHS Commissions towards reduction of predictive uncertainty, thus adding value to the activities and outcomes of PUB. In particular the IAHS Commissions are ideally placed to addressing the six basic questions of the Enabling Research programme, perhaps through affiliated **PUB Individual Projects**, in coordination with other similar programmes. On the other hand, it is also envisaged that one or more IAHS Commissions could join together and amongst themselves form fully fledged **PUB Working Groups** centred on particular river basins, applications, geographical regions or hydroclimatic zones etc., provided they are able to meet the minimum criteria presented above.

This flexible approach to engaging the IAHS Commissions ensures the greatest level of involvement of hydrologists around the world in PUB and PUB related activities, without losing the coherence and the single-minded focus on the key, main objectives. In return, through their involvement in PUB, the IAHS Commissions as well as the IAHS itself, gain by the increased focus, coordination and collaboration that are engendered across the various sub-disciplines of hydrologic science.

Links Between PUB and IAHS Commissions

ICSW - International Commission on Surface Water
ICGW - International Commission on Groundwater
ICCE - International Commission on Continental Erosion
ICSI - International Commission on Snow and Ice
ICWQ - International Commission on Water Quality
ICWRS - International Commission on Water Resources Systems
ICRS - International Commission on Remote Sensing
ICASVR - International Commission on Atmosphere-Soil-Vegetation Relations
ICT - International Commission on Tracers
WG:TH - Working Group on Theoretical Hydrology
WG:2020 - Hydrology 2020 Working Group

Links to Other International Programmes on Climate and Water

Currently, there exist a number of international programmes engaged in research related to water and environmental management at basin scale, and water and energy circulation at planetary scale. While these programmes may have different mandates, and thus may address different scientific questions, many have overlapping areas of interest with PUB. Examples include activities under UNESCO's International Hydrological Programme (IHP) and World Water Assessment Programme (WWAP), and WMO's Hydrology and Water Resources Programme (HWRP).

Water and Environmental Management at Basin Scale

Some international programmes have objectives that complement the science questions underpinning PUB (i.e., enabling research), thus presenting opportunities for close scientific collaboration and exchanges. Other programmes focus on developing improved techniques for water and environmental management through advances in hydrologic science, and the consequent upgrading of water policy. Therefore, links to

these programmes offer great opportunities for PUB to demonstrate its societal relevance by contributing the advances in predictive capability resulting from PUB towards applications in water management.

a) UNESCO World Water Assessment Programme (WWAP)

WWAP is an international programme tasked to produce an integrated and comprehensive global picture of freshwater quantities to support rational decision-making and management. The programme currently focuses on terrestrial freshwater, but will subsequently link with the marine near-shore environments and coastal zone regions as principal sinks for land-based sources of pollution and sedimentation and as areas where the threat of flooding and the potential impact of sea level rise on freshwater resources is particularly acute. This world freshwater assessment involves carrying out the following tasks: (i) data compilation (geo-referenced databases); (ii) supporting information technologies; (iii) data interpretation; (iv) comparative trend analyses; (v) data dissemination; and, (vi) methodology development and modelling. WWAP also involves the building of capacity in education and training, monitoring and database science and technology, improving country-level assessment, and assessment-related institutional management.

b) UNESCO International Hydrological Programme (IHP)

The objectives of IHP are to stimulate stronger relationships between scientific research, application and education. During 2002–2007, IHP will concentrate its activities on water systems at risk and the associated social challenges through its five themes (global changes, watershed dynamics, regional perspectives, water and society, and knowledge transfer), all of which are directly relevant to PUB.

c) Hydrology for the Environment, Life and Policy (IHP-HELP)

HELP, a component programme within IHP, aims to integrate hydrological science with societal issues and provide the scientific basis for improved land and water management, through a global network of experimental basins. HELP fosters process hydrology studies up to the meso-scale to address both water quantity and water quality problems behind the policy issues relevant to water resource management. A particular objective of HELP is to more closely integrate the needs of modelling with new experimental designs in the field to parameterize the effects of small-scale heterogeneity, especially with regard to lateral water flows and chemical fluxes. Due to its recognition of inter-annual to inter-decadal variability of climatic inputs and hydrologic responses, HELP emphasises in its activities the need for long-term experimental hydrology data sets in so-called HELP Basins to address the prediction of extremes.

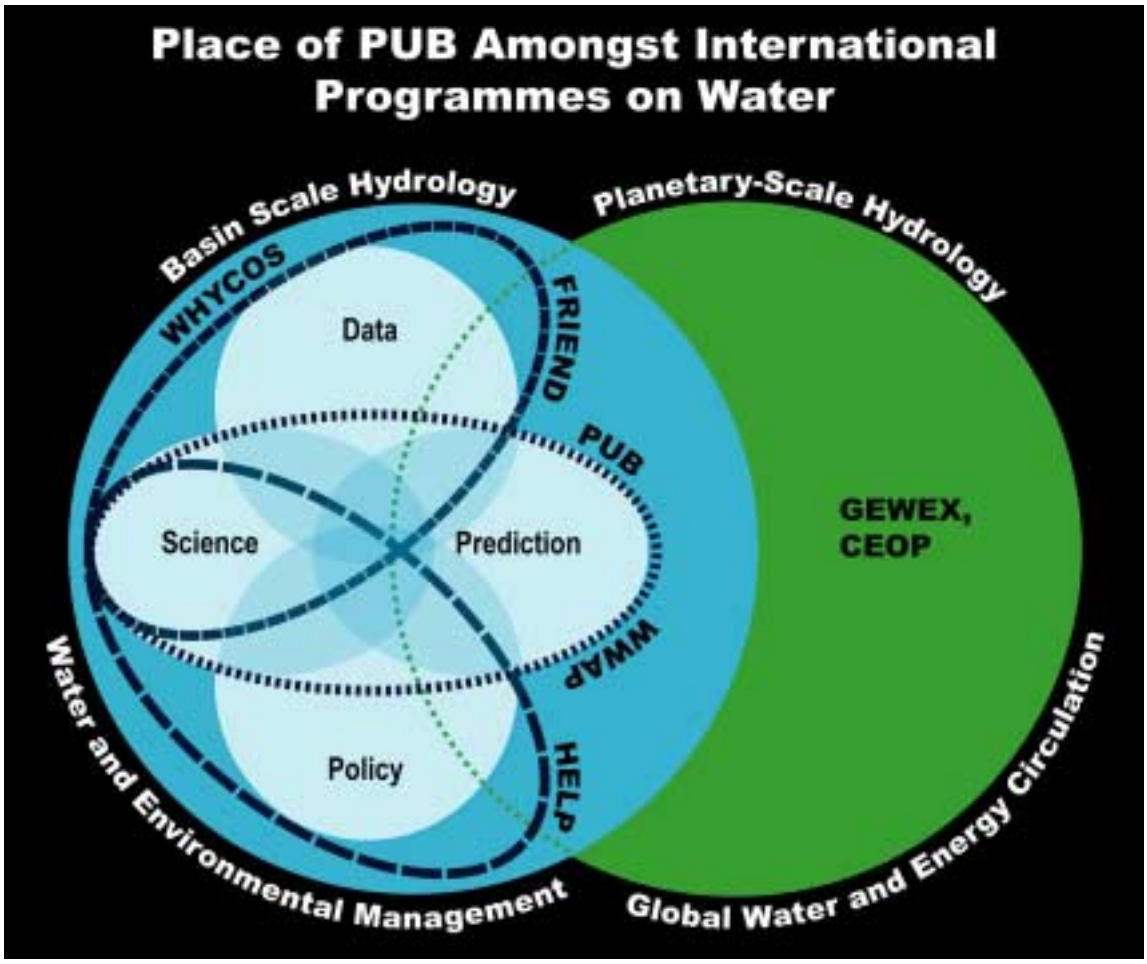
d) Flow Regimes from Experimental and Network Data (IHP-FRIEND)

The primary aim of FRIEND, another component programme within IHP, is to develop, through mutual exchange of data, knowledge and techniques, an understanding of hydrologic variability and similarity across the world. FRIEND research has a strong focus on the analyses of existing high quality data sets connected with low flows, floods, flow regimes, and rainfall-runoff modeling, all of which are linked with climate change and land use impacts. To date, eight regional FRIEND groups have been established in Northern Europe, Alpine and Mediterranean regions, Southern Africa, Nile Basin, West and Central Africa, Hindu-Kush Himalayan region, Asia-Pacific and the Caribbean.

e) WMO World Hydrological Observing System (WHYCOS)

WHYCOS is an activity of the Hydrology and Water Resources Programme (HWRP) within WMO. The WHYCOS objectives include: 1) strengthening the technical and institutional capabilities of national hydrological services to capture and process hydrological data and meet the needs of their end users for information on the status and trend of water resources; 2) establishing a global network of national

hydrological observations that provides information of a consistent quality, transmitted in real time to national and regional databases; and, 3) promoting and facilitating the dissemination and use of water-related information, using modern information technology.



.Water and Energy Circulation at the Planetary Scale

Public policy at all levels now requires hydrologists to reduce uncertainty caused by variability of terrestrial and atmospheric processes at both planetary and regional scales, including the influences of both natural and anthropogenic environmental change. Therefore it is crucial that results of global and regional models of environmental and climate variability and change be translated into predictions at basin scale, in terms of variability and changes of soil moisture regimes, groundwater recharge, runoff volumes, floods, droughts, lake levels, and soil erosional patterns. PUB will therefore need to interface with those global programmes that are involved in observing, understanding and modelling of the hydrologic cycles at planetary and regional scales.

a) Global Energy Water Cycle Experiment (GEWEX)

The Global Energy and Water Cycle Experiment (GEWEX) is a program initiated by the WMO's World Climate Research Programme (WCRP) to observe, understand and model the hydrological cycle and energy fluxes in the atmosphere, at the land surface and in the upper oceans. GEWEX is an integrated

program of research, observations, and science activities ultimately leading to the prediction of global and regional climate change.

The goal of the GEWEX is to reproduce and predict, by means of suitable models, the variations of the global hydrologic regime, its impact on atmospheric and surface dynamics, and variations in regional hydrologic processes and water resources and their responses to changes in the environment. Of particular relevance to PUB, GEWEX will help provide an order of magnitude improvement in the ability to model changes in global precipitation and evaporation variability, arising from the increase of greenhouse gases. GEWEX is now implemented and operating in six large river basins around the world (GCIP, MAGS, LBA, BALTEX, GAME, CATCH).

b) Coordinated Enhanced Observing Period (CEOP)

CEOP is a particular research activity coming under the umbrella of GEWEX. Its scientific objective is "to understand and model the influence of continental hydroclimatic processes on the predictability of global atmospheric circulation and changes in water resources, with a particular focus on the heat source and sink regions that drive and modify the climate system and anomalies." It has two implementation objectives. The first is " to use enhanced observations to better document and simulate water and energy fluxes and reservoirs over land on diurnal to annual temporal scales and to better predict these on temporal scales up to seasonal for water resource applications." The second implementation objective is "to document the seasonal march of the monsoon systems, assess their driving mechanisms, and investigate their possible physical connections." CEOP operates by concentrating on a number of basins (i.e., CEOP basins) in key parts of the world.

Synergies Between PUB and Related Programmes

PUB benefits in a number of ways by linking up with the international programmes described above, and with many others.

- Through links with science projects organised under HELP, and with a number of IAHS International Commissions, PUB benefits in advancing the research on a number of enabling research questions. These include advances in process understanding, model development and testing in meso-scale HELP basins, and the application of tracer studies for understanding runoff processes.
- By having access to real basins around the world, such as HELP and FRIEND basins, and by linking with projects that address the links between science and policy, as in HELP projects, PUB brings valuable social relevance to its research outcomes.
- By accessing data and analyses relating to basin responses in different hydroclimatic regions of the world, as in the case of FRIEND basins, PUB achieves one of its core objective of understanding the similarity and differences between basins of the world in terms of the underlying climate-soil-vegetation controls, and a harmonisation of modelling approaches available for predicting in ungauged basins.
- By linking with data-oriented programmes such as WHYCOS, PUB benefits by highlighting the data requirements for predictions in data-poor regions of the world, and the improvements in predictive capability that can be achieved through additional and targeted gauging.
- By linking with WWAP, PUB is able to deliver its entire range of scientific expertise and available data resources to make quantitative assessment of the available freshwater resources of the world, and in doing so identify the gaps in knowledge and information that impact on the reliability of the predictions so obtained.

- By linking up with GEWEX and CEOP, PUB benefits in terms of increased understanding of the causes and effects of natural variability of hydrologic forcing variables at multi-annual and multi-decadal time scales, and the effects of human-induced climate change, on basin scale responses.
- By linking up with the global network of scientists and basins associated with these international programmes PUB benefits by being able to achieve its capacity building objectives.

In summary, the links with the IAHS Commissions and other international programmes are extremely critical to advancing the scientific, societal and capacity building objectives of PUB. Indeed, PUB will not meet these objectives by working in isolation.

Network of PUB, PUB-HELP, PUB-FRIEND & PUB-CEOP Basins

It is envisaged that a number of PUB Working Groups formed around selected basins in a variety of hydroclimatic regions of the world. Provided that these basins meet strict quality control criteria they will then qualify as PUB Basins. The WGs will be encouraged to make this data available in the public domain, preferably via the World-Wide Web, with the view to encouraging wider applications and comparability of a variety of prediction approaches that utilise these datasets. PUB will actively foster this activity and give it high visibility through rapid communication of the results of all collaborative research activities enabled by it.

PUB will also work closely with HELP, FRIEND, CEOP, GEWEX etc. as 1) networks of basin centred studies have been established within these programmes, and 2) the advances in predictability arising from PUB can be utilised automatically in these linked programmes for the benefit of mankind. Some of the basins established within these programmes can be considered for setting up as PUB Basins, provided they satisfy the required quality criteria, and made available for PUB related studies. In this way PUB-HELP, PUB-FRIEND, PUB-CEOP and PUB-GEWEX basins will have been set up in all parts of the world.

The links with and use of HELP experimental and monitoring basins will help PUB address some of its fundamental science questions related to process heterogeneity and consequent impacts on predictive uncertainty, while also gaining in terms of societal relevance of its outcomes. The links with the GEWEX-CEOP basins will assist PUB to address the larger scale processes connected with the vertical exchange of energy and water vapour at macro-scale basins or over large regions. The links with and use of FRIEND basins will enhance the objective of PUB to analyse and learn from hydrological data collected in different hydroclimatic zones of the world, and to understand variability and similarity of basin responses in terms of the underlying climate, soil, and vegetation controls.

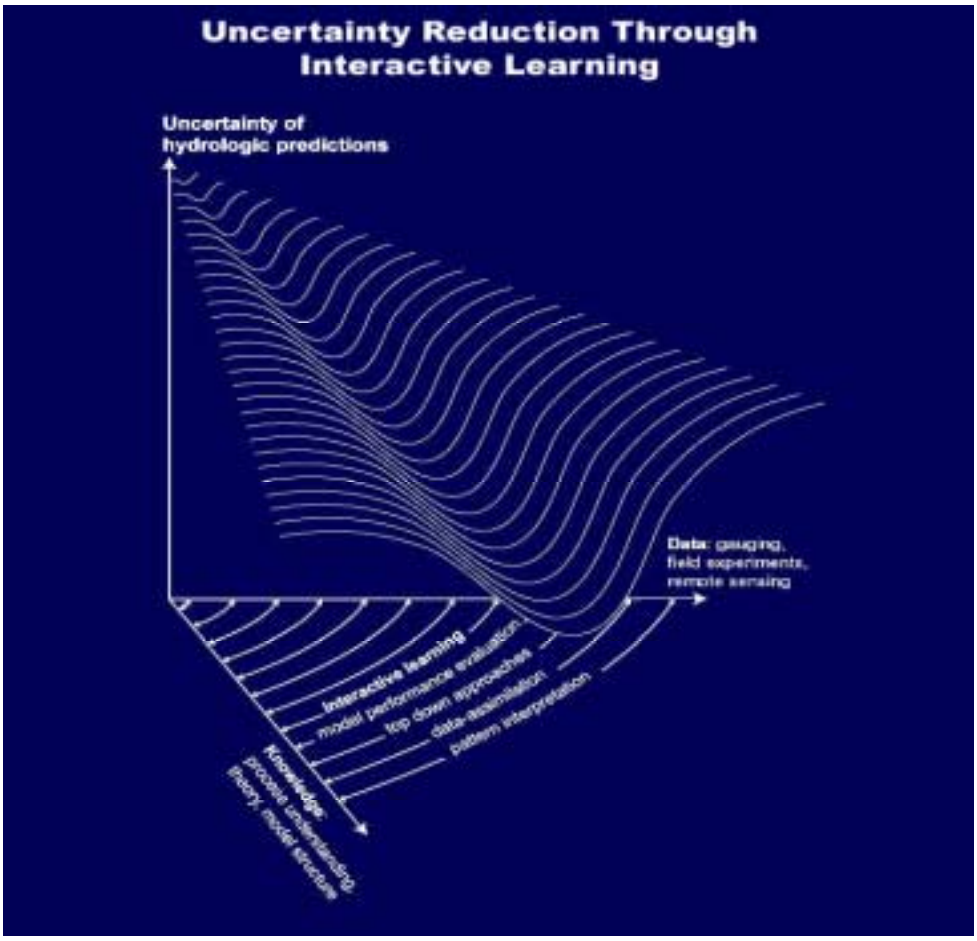
Minimum data quality criteria will be presented here only in a preliminary manner, and will be developed further by the SSG in partnership with various PUB Working Groups. The criteria will differ with the nature of applications and hydroclimatic regimes. At the minimum, the data must enable reliable computation of annual balance of the quantity of interest, be it water, sediments, nutrients etc. Continuous time series of data relating to rainfall, potential evaporation and streamflow must also be available, at least at the daily timestep, for a period of at least 10 years, with flood records available for at least 30 years. The available datasets must also include digital terrain information relating to topography, soils, vegetation and land use.

All data must be available publicly, not only to members of the associated Working Groups, but more widely so that the data can be used by the hydrologic community worldwide for a comparison of modeling approaches and to perform comparative analysis of basins in different hydroclimatic regions of the world.

MAIN PUB AND PUB-SPONSORED ACTIVITIES

1. RESEARCH ACTIVITIES

PUB will foster and spearhead targeted research programmes through the activities of affiliated PUB Working Groups. These could be centred on selected PUB Basins in different geographic or hydroclimatic regions of the world, or on various hydrologic applications. The research will focus on three clear targets: 1) evaluate the performance of existing prediction techniques in terms of predictive uncertainty, 2) demonstrate the value of data, knowledge and understanding for reducing predictive uncertainty, 3) understand the hydrological functioning of basins at different scales in different hydro-climatic regions, leading to a harmonisation of models and prediction methods appropriate for these regions for specific applications. The details of these three core research targets are given below:



Target 1: Evaluate the performance of existing hydrological models and prediction techniques in terms of predictive uncertainty

PUB will establish a new scientific framework for evaluating the performance of existing hydrological models and prediction techniques that are, or could be, used in ungauged basins, in the context of the uncertainty in their predictions. The relative importance of factors controlling predictive uncertainty will be investigated, namely, climate inputs, landscape properties and model parameters, and model structure and process descriptions. In the short term, PUB will also quantify, in a more scientifically rigorous manner than done heretofore, the inadequacies of existing models and modelling approaches so as to provide signposts for new scientific developments.

Target 2: Demonstrate the value of data, knowledge and understanding for reducing predictive uncertainty

PUB will demonstrate the value of alternative types of data, knowledge and process understanding for reducing predictive uncertainty, thus providing guidance for data collection programmes, new remote

sensing developments, and new ground–based instrumentation and targeted field experiments, and for using widely available digital data sets effectively for predictions. Advances in data availability, knowledge, and process understanding will be utilised towards targeted efforts to reduce the uncertainty in the longer-term.

Target 3: Understand the hydrological functioning of basins at different scales in different hydro-climatic regions

PUB will have a major thrust to understand the hydrological functioning of basins at different scales, to identify which processes are dominant or controlling at different scales in the different hydroclimatic regions of the world, to determine how hydrologic functioning controls, or constrained by, ecological functioning, atmospheric exchanges, to estimate fluxes of water, sediments and nutrients to the oceans etc, and to determine how human activities can impact on the functioning of basins and associated ecosystems. PUB will also explore how the strengthened scientific and predictive capability will contribute to improved management of water and the environment.

PUB Core Research Projects and Task Forces

In order to achieve these targets within the stipulated 10-year period, PUB will organise itself into 8 cross-cutting **Core Research Projects**. Each project will be driven by a **Project Task Force**, which will consist of active members or leaders of PUB Working Groups that are appropriate or relevant to that Project, and other members co-opted on the basis of their potential contributions. Each Project Task Force will have an elected **Task Force Convenor**, chosen by the Task Force members themselves. It is envisaged that in the early formative stages an **Interim Convenor** may be appointed by the SSG from amongst its present membership or from outside. Brief summaries of the eight **Core Research Projects** are described below.

1. Uncertainty Estimation Project: PUB-UEP
Project for Comparison of Uncertainty Estimation Methods

Uncertainty is at the core of all PUB research activities, and yet PUB is fully aware that the routine adoption of predictive uncertainty is low at this early stage. Therefore, systematic efforts will be made, initially by the SSG in a pro-active manner, to make available to the hydrologic community a wide range of alternative methods for uncertainty estimation, including those being used in sister disciplines such as meteorology, groundwater hydrology, ecology, geophysics and economics, to enable rigorous comparisons of the various methods for adoption to solve typical hydrologic prediction problems.

2. Model Comparability Project: PUB-MCP
Project for Comparability and Harmonisation of Models and Prediction Approaches

One of the cornerstones of PUB is the reduction of predictive uncertainty, especially reduction of model structure uncertainty, through comparisons of different models and modelling approaches and learning about their strengths and weaknesses through carefully designed diagnostic studies. There is already considerable ongoing activity in this area, through the MOPEX and DMIP programmes. Therefore PUB will actively collaborate with these and other programmes and design joint activities aimed at improving the conceptual basis and process descriptions for a variety of models and applications.

3. Uncertainty Reduction Project: PUB-URP
Project for Uncertainty Reduction through Assimilation of Data, Knowledge and Understanding

This project focuses on methods for reducing predictive uncertainty through the assimilation of new data sources for parameter estimation, new knowledge of processes, process understanding and quantitative descriptions that may arise from focused field experiments at various scales, and information and theories

from cognate fields which overlap with hydrology, such as ecology, geomorphology, meteorology and groundwater hydrology. Special efforts will be made to form links between heterogeneity and uncertainty, including limits to predictability. This activity will link up with other global activities being carried out under other related programmes, such as HELP, ECOHYDROLOGY, JIIHP, CHASM, CUAHSI, LOCAR etc. to name a few.

4. Hydroclimatic Classification Project: PUB-HCP
Project for Hydroclimatic Classification of Basins and Harmonisation of Prediction Methods

This project will aim to collect and analyse data from various parts of the world, in different hydroclimatic zones, with the aim of understanding the climate-soil-vegetation controls on the similarity and differences between the responses of these basins, and a basin classification system that will assist towards the harmonisation of models and modelling approaches presently used in these hydroclimatic regions for various applications. This is an activity that has a lot in common with programmes such as FRIEND and therefore will be carried out in coordination and partnership with such programmes.

5. Virtual Collaboratories Project: PUB-VCP
Project for Virtual Collaboratories and Field Experiments

PUB will need a coherent programme of research of using models to explore productive avenues to reduce uncertainty, and virtual modelling collaboratories and field experiments show a lot of potential in this regard. A number of ideas have been proposed in this regard: 1) using simple models (i.e., caricatures) that capture the essence of the problem, but not all the details, and are falsified using patterns in observed data; 2) models incorporating key hydrologic processes that can be used as virtual experimental laboratories by modellers and experimentalists to explore first-order controls on basin responses; and 3) linked hierarchical suite of models characterizing runoff production, sediment and contaminants, and their transport within basins, that can be used to assist in harmonised models and modelling approaches.

6. Environmental Change Project: PUB-ECP
Project for Prediction of Effects of Natural Climatic Variability and Climate and Land Use Changes

One of the greatest complicating features of hydrologic predictions in the future is that predictions are increasingly likely to include the effects of natural multi-annual and multi-decadal variability of climate inputs, and the effects of human-induced changes to both climate and landscape properties. PUB will therefore have research projects that deal explicitly with these questions, so that adequate attention is paid to these difficult issues and specific methods are developed to deal with them. PUB will interact extensively with programmes such as GEWEX and CEOP that have a sharper focus on global change issues, to benefit from the data sources, expertise and methods developed through these programmes.

7. Data Collection and Assimilation Project: PUB-DCP
Project for Enhancement of Data Collection and Data Assimilation Programmes

The ultimate benefit of PUB for hydrology is that through its focus on predictive uncertainty, the value of hydrologic data is able to be assessed, and through highlighting the links between data and reduction of predictive uncertainty, we are then able to influence water managers and agencies responsible for the routine hydrologic measurements to invest in increased, perhaps highly targeted measurements in the future, including through remote sensing. Therefore PUB will organise a research project that is focused on data collection, and the assimilation of different data resources towards the reduction of predictive uncertainty. In this respect, PUB will link up with existing global and national programmes, such as WHYCOS, CEOP, and other activities focused on remote sensing and data assimilation.

8. Capacity Building Project: PUB-CBP
Project for Capacity Building Programmes Through Global Partnerships

It is extremely important that the outcomes of PUB, in terms of advances in the capability to make reliable predictions, actually reach the user community, including those in data-poor regions. With this in mind, PUB will have active involvement in existing and new projects that enable the outcomes of PUB to be transferred to the user community. These projects will be carried out in partnership with various IAHS International Commissions, and global programmes such as HELP, FRIEND and WWAP, which already have highly focused strategies for doing this. PUB will complement these with outreach activities, such as short courses, use of the website, and global partnerships centred on PUB Working Groups.

Capacity Building Through Global Partnerships

One of the greatest benefits of PUB is the increased level of knowledge and capability that will be generated out of the sustained research that will done globally on hydrologic predictions. PUB has the ambition to make these advances spread as uniformly as possible throughout the world. Therefore, "capacity building" will be a significant component of PUB activities. PUB will achieve the aims of capacity building through the following initiatives and activities:

- Actively encourage PUB Working Groups to be formed in both developed and developing countries, in all continents;
- Encourage all PUB Working Groups to include scientists from both developing and developed countries as active partners, in order to encourage training opportunities and active collaborative links across the north-south divide;
- Actively encourage and foster conferences, workshops and targeted short courses to be run in developing countries, so that the excitement and recent advances arising from PUB can be communicated and shared with scientists everywhere;
- Actively utilise existing people networks that have been established through HELP, FRIEND, GEWEX etc., the various IAHS Commissions, and other global programmes;
- Link up with existing networks of HELP, FRIEND and CEOP river basins established in developing countries and adopt them as PUB basins, and use these for collaborative projects, training exercises, and other capacity building activities; and
- Support and sponsor, where possible, the active participation of scientists from developing countries in all PUB activities, as well as in PUB-sponsored conferences and workshops.

2. RESEARCH COMMUNICATION, OUTREACH AND LOBBYING

As the research into PUB takes hold, the main PUB activities will be in three areas:

1. organization of meetings, workshops and congresses,
2. regular publication of progress in PUB activities, and
3. Technology Transfer through various means, but with a specific focus on Web-based communication.

These activities will be led, in the main, by the PUB Science Steering Group (SSG). However, the SSG will also work closely with other national and international organisations (AGU, EGS, BHS etc.) and ongoing national and international programmes (IHP, GEWEX, HELP, FRIEND etc.), and all IAHS Commissions, to co-sponsor related activities that may have a direct relevance to PUB.

2.1. Meetings

Conferences (regular)

IAHS/SSG once every two years
Seek to integrate results from individual WGs
(integrative hydrology)
Progress meetings (for discussion)

Specialist Workshops (ad hoc) - AGU/EGS/MODSIM/BHS/etc

comparability of models/approaches/catchments
uncertainty explicitly encouraged/included
progress evaluation
consensus building within individual WGs/Thematic issues
regular progress meetings

Informal uncertainty workshops (Proactive promotion/education of uncertainty)

aimed to promote the utilisation of a range of uncertainty methodologies
raise the level of awareness and employment of range of techniques
focus on promoting simple techniques to non-specialist users (not theoretical discussion with respect to rainfall-runoff) -- to be done necessarily early within PUB initiative
Emphasis on a range of applications across IAHS
Encourage non-specialists to present simple case studies
plurality of approaches is important, empowering community to make realistic assessment of uncertainty

International Stakeholder Conference (sometime in 2007-9)

'The uncertainty of hydrology and the value of data'
take stock of progress in PUB activities
assess quantification of uncertainty
connection between data, uncertainty and process understanding
obtain feedback from users of hydrologic predictions
identify future data needs and process research
bring together national organisations responsible for data collection
funding agencies and scientific societies
representatives of other related programmes (HELP/IHP/WMO)

2.2 Publications

1-2 IAHS redbooks per 2 years arising from IAHS/SSG Biennial conferences
redbooks should integrate research/progress (focus on comparability)
raise profile of IAHS redbook series
no more than 1 'special issue' or 1-2 'special sections' of HSJ
When HSJ/redbooks cannot accommodate volume of material, individual WG encouraged to publish in the wider hydrological community (special issues)
These may be somewhat more specialised eg. thematic PUB groups (fractals/CHASM etc.)

2.3 Technology Transfer and Web-Based Communication

News and Views

Science implementation plan
Members of SSG and SAG
Meetings - Past and Future
List of WGs (Definition of aims, data sets employed)
Links to PUB datasets

Links to related activities

Message Board

Ongoing Call for Proposals to set up PUB Working Groups (pro forma)

Technology Transfer (Web)

Directory of methodologies

Directory of expertise for consultation

Directory of relevant data sources

Technology Transfer (workshops/short courses)

Encourage organisation of workshops in Less Developed Countries

Encourage organisation of short courses summarising information on lessons learnt from PUB activities

3. Coordination of PUB Activities and SSG Organisational Chart

The SSG is tasked with the primary responsibility for leading, planning, and implementing the PUB initiative, especially with regard to scientific aspects of the program. Nevertheless, as a practical measure, the role of the SSG is to act as a catalyst to inspire, lead and coordinate PUB activities, and to retain its coherence, and in this respect to ensure that all niches within the PUB research programme are filled.

The SSG will pursue its research objectives through numerous PUB Working Groups formed spontaneously around the world, which will be the engines through which PUB objectives will be realised. The SSG will take a lead role in the setting up of affiliated Working Groups, give visibility to their activities, and foster interactions and exchange of information between the different Working Groups.

It should be noted that while individual members of the SSG may very well be members or even leaders of PUB Working Groups, the SSG is not a PUB Working Group *per se,* and should not be expected or automatically assumed to lead any specific research efforts on its own.

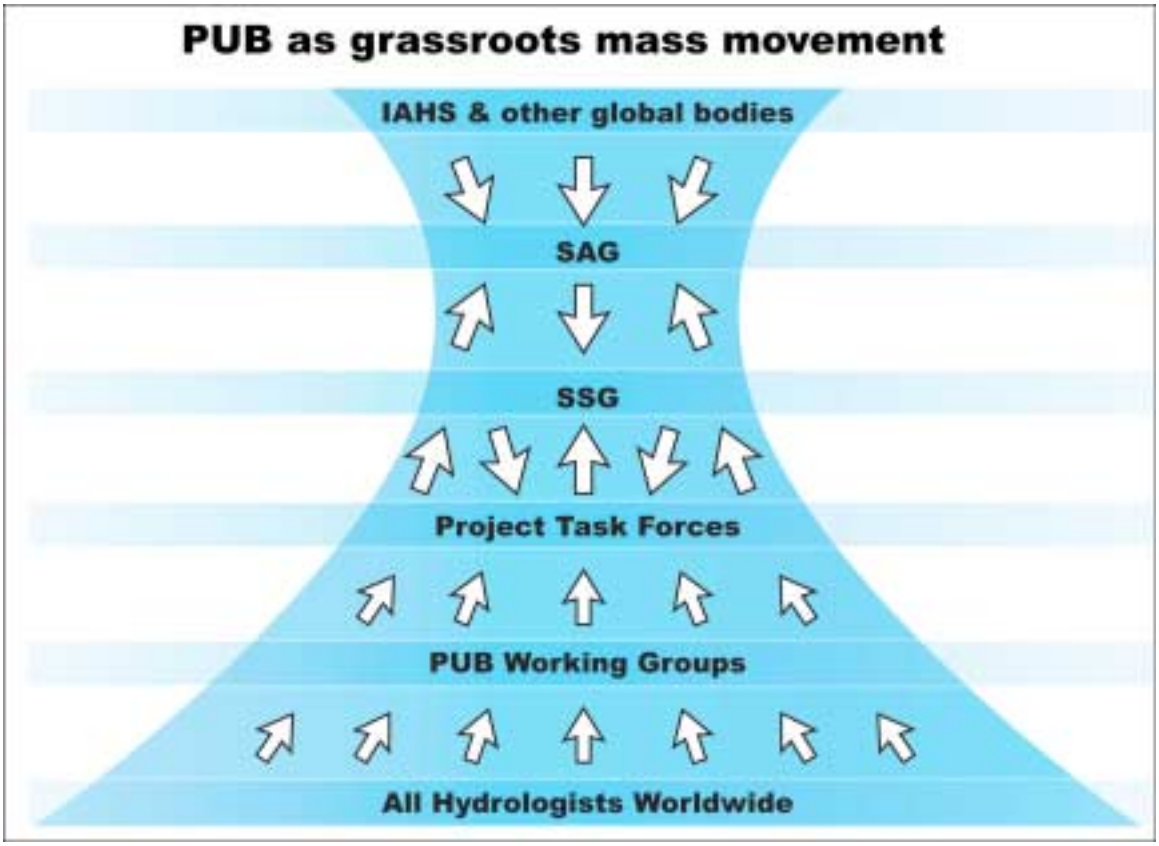
The SSG will forge strong links with all IAHS Commissions and international programmes such as HELP, FRIEND, CEOP and GEWEX, so that PUB can synergistically benefit from their activities, expertise, and associated people networks. As the research carried out by the PUB Working Groups unfolds, the SSG sees its subsequent role as one of coordinating these research activities, and communicating the research outcomes through conferences and workshops, with a particular emphasis on short courses. PUB will also take a pro-active role in propagating advances in prediction approaches and methods of uncertainty analysis for the benefit of users and researchers worldwide. Finally, in association with the SAG, the SSG will also make efforts to advise and lobby national and international research funding agencies, in order to ensure that PUB-related research programmes are adequately funded.

Based on the broad perspective presented above, for organisational purposes, the various activities of the

SSG are divided into the following 11 coordinating tasks:

- Coordination of PUB Working Groups
- Coordination of PUB Activities/Conferences
- Coordination of PUB/HELP Basins
- Coordination of PUB Lobbying & Publicity
- Coordination of PUB Communication - Website
- Coordination of PUB Capacity Building
- Coordination of Link to IAHS Commissions and User Groups
- Coordination of Links to HELP, FRIEND etc.
- Coordination of Links to GEWEX, CEOP, WHYCOS etc.
- Coordination of PUB Publications
- Central Coordination and Links to SAG

Central coordination involves coordination of the activities of the large number of PUB Working Groups formed around the world. To establish greater coherence to its core research programme, and to provide organisational structure, the SSG will pro-actively form a number of **Project Task Forces**, consisting of representatives of PUB Working Groups, and other co-opted members, to plan, lead and coordinate the various **PUB Core Research Projects** outlined previously. It is envisaged that in the initial, formative stages, SSG members may be asked to become **Interim Convenors** of these Task Forces. However, in the course of time this responsibility will shift to **Project Convenors** elected from amongst members of the Task Forces, in which case the SSG representative will provide continuity, and linkage to the SSG and to other Task Forces as well, leading to better coordination of all PUB activities. However, regardless of the mechanisms adopted by each Task Force, the self-organising and grass-roots character of these Task Forces, and PUB activities in general, will not be compromised.



4. Timeline: Activities, Milestones and Outcomes

Phase 1 (planning and preparation phase): 2004-2006; Phase 2 (maturation phase): 2007-2009; Phase 3 (concluding phase): 2010-2102.

Year	Activity	Milestones, Outcomes
2003	IUGG General Assembly, Sapporo, Japan Launch PUB SSG Website Ad hoc meetings/conferences: AGU, EGS etc.	Adopt PUB Science Plan Start discussion forum Expand the coverage of PUB

2004	Start registering PUB Working Groups Special Issue of HSJ on PUB Ad hoc meetings/conferences: AGU, EGS etc.	Data on PUB basins made accessible via the WWW Compendium of invited reviews on PUB issues and approaches Technology Transfer
2005	IAHS General Assembly + Workshops on uncertainty 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Workshops/Symposia on Performance Evaluation of Existing Prediction Methods Technology Transfer on Predictive uncertainty: Publication of 2 Redbooks Expand the coverage of PUB
2006	Major International Conference on Approaches to Predictive Uncertainty 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Publication of 2 Redbooks summarizing the progress on various issues in PUB Technology Transfer on Predictive uncertainty Expand the coverage of PUB
2007	IUGG General Assembly 1 regional workshop/short course Survey of Progress Towards PUB from the planning phase (2004-2006) Ad hoc meetings/conferences: AGU, EGS etc.	IAHS Symposia/Workshops on Worth of Data, Knowledge and Understanding on Uncertainty Reduction Technology Transfer on Predictive uncertainty Interim Report on PUB: HSJ Journal special issue/Redbook based on the planning phase (2004-2006) Expand the coverage of PUB
2008	Stakeholder Conference on PUB 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Conference on Uncertainty and Value of Data (ICSU, NSF, ARC, NERC, EU) Technology Transfer on Predictive uncertainty Expand the coverage of PUB
2009	IAHS General Assembly 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Workshops/Symposia on Hydrological Functioning of Basins in Different Hydroclimatic Regions Technology Transfer on Predictive uncertainty Expand the coverage of PUB

2010	Major International Conference on PUB in a Developing Country + Short Courses 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Taking stock from the maturation phase (2007-2009) Midterm report on the maturation phase in the form of a HSJ special issue/redbook Technology Transfer on Predictive uncertainty Expand the coverage of PUB
2011	IUGG General Assembly 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	IAHS Workshops/Symposia on Predictions in Ungauged Basins Technology Transfer on Predictive uncertainty Expand the coverage of PUB
2012	Major International Conference on PUB in a Developing Country + Short Courses 1 regional workshop/short course Ad hoc meetings/conferences: AGU, EGS etc.	Technology Transfer and Looking Ahead Recommendations for implementation including discussions and impacts for the future Publication of a "final" report in the form of a book Expand the coverage of PUB

5. Expected Outcomes and Benefits of PUB

Expected outcomes and what comes after PUB

- routine estimation of predictive uncertainty across the hydrological sciences,
- new impetus and investments in traditional measurements (gauging) and field experiments integrated with new measurement technologies such as remote sensing
- new suite of harmonised models and methodologies for predictions in ungauged basins around the world in different hydroclimatic zones, and increased capability to predict and manage water resources and water quality
- a revitalized and unified field of hydrology, especially basin scale hydrology, with an increased level of expertise worldwide
- a network of working groups and scientists focused around a set of river basins around the world with the necessary scientific expertise and experience to solve different hydrological problems
- ready for a new initiative or a new decade on devoted to predictions of water quality in association with ecology
- A network of continuously measurement stations in selected basins around the world and associated databases of hydrological measurements and data to serve as a reference pool for new emerging questions.
- Benefits to science are greater coherence of the science agenda, coordination and harmony of scientific activities, and increased prospects for breakthroughs and excitement for the science.

Proposed PUB Activities for 2003-2005

The period 2003-2005 will cover the preparatory phase of the PUB initiative. It is hoped to carry out the following activities to fully launch the initiative:

Launch of the PUB Science and Implementation Plan

The Science and Implementation Plan will be submitted for approval at the IAHS Bureau Meeting during the IUGG Congress in Sapporo, Japan. On approval the plan will be launched through publication in the Hydrological Sciences Journal during 2003.

Formation of Working Groups and Task Forces

Repeated calls and expressions of interest will be made during the Sapporo meeting and afterwards, and it is hoped to register at least 15 PUB Working Groups before 2005. PUB Task Forces will be formed with inputs from the Working Groups themselves to drive the various PUB Core Research Projects. We expect to have these ready and in operation before the end of 2004.

Organisation of Conferences and Workshops

A number of conferences and workshops are already in train, or are in planning stages. Examples include special sessions at the AGU and EGU Meetings in 2003 and 2004, at the IEMSS meeting in Osnabrück, Germany in June 2004. In addition, a workshop is being planned in Perth, Australia, in January 2004 to launch the Australian and Japanese PUB Working Groups.

Publications, Publicity and Lobbying

A number of publications are in train or are being planned:

- Invited paper in HESS journal (Sivapalan's John Dalton Lecture at EGU), October 2003
- A number of HP Today invited commentaries (2003 and 2004)
- Articles in EOS (AGU newsletter), the EGU, BHS and ATSE newsletters: 2003 and 2004
- Science and Implementation Plan published in Hydrological Sciences Journal of the IAHS, 2003
- Special issue of Hydrological Sciences Journal (August 2004)
- Redbooks arising from Brasilia meeting
- Handbook/Book and User Manual on Uncertainty Estimation Methods

Specific Targets for July 2005

July 2005 will represent the end of the preparatory phase of PUB. With this in mind, we believe the following are reasonable targets to aim for by mid-2005 in time for the IAHS General Assembly in Brazil.

- Formation of at least 15 PUB Working Groups around the world
- Formation of at least 30 Individual Projects around the world
- Formation of all PUB Core Research Projects and Project Task Forces
- Special session on PUB at the IAHS General Assembly organised in terms of PUB Core Research Projects and convened by the respective Project Task Forces.
- Adoption of uncertainty estimation in a majority of papers presented
- A special issue of Hydrological Sciences Journal devoted to PUB through invited review articles, and a book/handbook and user manuals for a suite of uncertainty estimation methods, and at least 2 Redbooks.

PUB as Catalyst for Innovation and Scientific Breakthroughs

A number of unique and defining features inherent to PUB give it the capacity to lead to excitement and innovation in hydrologic research, and to act as catalysts for generation of scientific breakthroughs (Dunne, 1998):

1) PUB activities and organization have been designed to avoid fragmentation at all costs, and to pursue integration with vigour. Differences in skills between different groups of hydrologists are seen as resources rather than impediments.

2) Comparability of prediction methods is encouraged, indeed required, increasing communication between different hydrologic specialisations, leading to shared learning and experiences.

3) PUB is designed to profit from lateral perspectives into ancillary sciences, such as geomorphology, ecology, meteorology, etc. Since questions about basin responses are increasingly likely to be defined in broad multi-dimensional terms, the resulting cross-fertilisation of ideas and knowledge will lead to the discovery of new phenomena and insights.

4) The diversity engendered by encouragement of different forms of knowledge and different prediction approaches, combined with the coherence enforced by the uncompromising focus on uncertainty reduction, will lead to scientific breakthroughs as hydrologists will be encouraged, and indeed driven, to break out of their disciplinary isolation and collaborate in the unexplored territory between specialities.

5) PUB has found a delicate balance between what is fundamental and enduring and what is immediately useful in hydrology, by seeking to harness the power of science to provide society with the tools to manage the environment in a sustainable manner. This feature, combined with the greater coherence and diversity promoted by PUB, is likely to make hydrology an attractive field for young scientists.

6) PUB sees itself as operating in a “web” of information arising from nature, and societal concerns and needs related to the environment. It is therefore in a position to stimulate new ideas and feedback, and to provide opportunities for gaining support for hydrologic research.

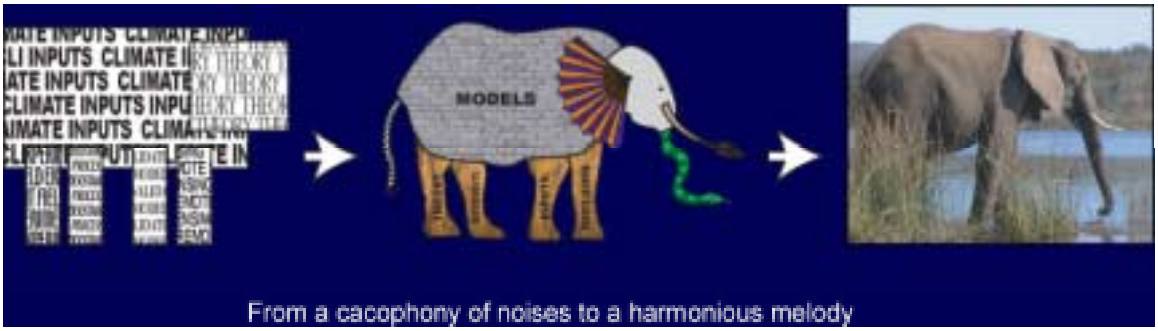
Guiding Principles Behind PUB Science and Implementation Plan

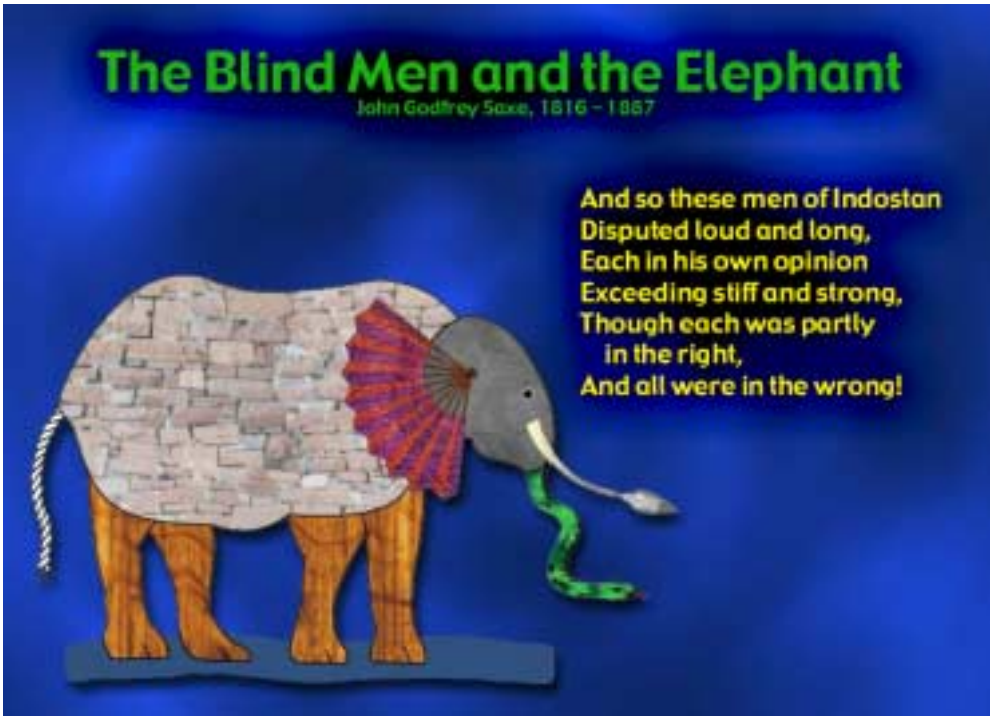
A number of key principles naturally arise from the broad community objectives presented before, and have guided the development of the science and implementation plan of PUB. Special gratitude to Dunne (1998) for the inspiration it provided.

- In view of its societal obligations, PUB will focus on real hydrologic phenomena, such as floods, droughts, eutrophication of receiving waters, degradation of natural ecosystems, effects of climatic variability and change and/or land use changes etc (after Dunne, 1998*);
- In being essentially a science initiative, PUB will mainly seek to advance fundamental knowledge of hydrological processes, even to the extent of going beyond the immediate problem solving needs or the community interest of the present time (after Dunne, 1998*);
- PUB will constantly focus attention on what is not known, indeed it will gain energy from its own uncertainties, emphasizing the need for empirical exploration and explicit attempts to validate or falsify new ideas (after Dunne, 1998*);
- PUB emphasizes learning from data from selected basins in different biomes or hydro-climatic regions, demonstrating the value of data and the need for future data requirements, and should not be seen as an alternative to data collection,
- PUB will be obligatorily be self-critical, and will include within it a strong element focused on continual assessment of its own progress, with the predictive uncertainty being used as the measure of progress (after Dunne, 1998*);
- PUB is necessarily integrative, will avoid and indeed overcome the fragmentation of approaches that has bedeviled hydrology in the past, and rather will seek convergence of a variety of approaches towards common objectives, also profiting from lateral perspectives into ancillary sciences (after Dunne, 1998*);
- Develop a hydrological prediction system that is capable of assessing the errors or uncertainty in model predictions, quantifying the different sources of the uncertainty – parameter estimates, climatic inputs and model structure – and constraining these uncertainties by making the best use of the information available from other sites and of measurement programs implemented at the site of interest.

*Dunne, T. (1998). Wolman Lecture: Hydrologic science …. in landscapes ….on a planet … in the future. In: *Hydrologic Sciences: Taking Stock and Looking Ahead*, National Academy Press, Washington, D.C., 138p.

Future Vision for the Culmination of PUB





John Godfrey Saxe's (1816-1887) version of the famous Indian legend,

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

The First approached the Elephant,
And happening to fall
Against his broad and sturdy side,
At once began to bawl:
"God bless me! but the Elephant
Is very like a wall!"

The Second, feeling of the tusk
Cried, "Ho! what have we here,
So very round and smooth and sharp?
To me `tis mighty clear
This wonder of an Elephant
Is very like a spear!"

The Third approached the animal,
And happening to take
The squirming trunk within his hands,
Thus boldly up he spake:
"I see," quoth he, "the Elephant
Is very like a snake!"

The Fourth reached out an eager hand,
And felt about the knee:
"What most this wondrous beast is like
Is mighty plain," quoth he;
"'Tis clear enough the Elephant
Is very like a tree!"

The Fifth, who chanced to touch the ear,
Said: "E'en the blindest man
Can tell what this resembles most;
Deny the fact who can,
This marvel of an Elephant
Is very like a fan!"

The Sixth no sooner had begun
About the beast to grope,
Than, seizing on the swinging tail
That fell within his scope.
"I see," quoth he, "the Elephant
Is very like a rope!"

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

Moral:

So oft in theologic wars,
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean,
And prate about an Elephant
Not one of them has seen!

Saxe, John Godfrey, (1963), "The Blind Men and the Elephant; John Godfrey Saxe's version of the famous Indian legend. Pictures by Paul Galdone," New York: Whittlesey House.