The PUB Top-Down Modelling Working Group (TDWG): initial development and activities

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Abstract Contributing to the Preparation and Planning phase (2004–2006) of the International Association of Hydrological Sciences (IAHS) Decade (2003–2012) for Prediction in Ungauged Basins (PUB), the paper describes the background, aims and initial activities of the Top-Down modelling Working Group (TDWG). It summarizes broad features of the top-down modelling approach for estimating hydrological variables at ungauged sites. Links likely to develop between the TDWG and other PUB Working Groups as the PUB Decade unfolds further are mentioned. The TDWG website is introduced, which is intended to encourage dialogue within the TDWG, PUB and more widely. The proposed INTRAPUB project (Information TRAnsfer for Prediction in Ungauged Basins) is outlined.

Key words PUB; regionalization; top-down modelling

INTRODUCTION

Background details of the IAHS PUB Decade (2003–2012), and its Science and Implementation Plan, are given elsewhere (the IAHS and PUB websites (http://iahs.info; and http://cee.uiuc.edu/research/pub/default.asp; Sivapalan *et al.*, 2003a). PUB Working Groups (WGs), registered with the PUB Science Steering Group (SSG), are the main engines of PUB research activities. The Top-Down modelling Working Group (TDWG) is one of several WGs formed during the Preparation and Planning phase (2004–2006) of the PUB Decade. Following an earlier proposal (Littlewood *et al.*, 2002) from an international group of researchers already working with top-down rainfall–streamflow models for prediction in ungauged basins (regionalization), an embryonic TDWG was formed in 2003. Group membership now stands at 47 from 16 countries. The paper provides a record of the development and activities of the TDWG to April 2005, and looks to its future as the PUB Decade unfolds.

After this Introduction, the following sections introduce top-down modelling in the context of the PUB Decade, and describe recent activities and representation of the TDWG at conferences, workshops, etc. The TDWG website and Newsletters are then introduced and the first project (INTRAPUB) proposed by a few members of the TDWG is outlined. Concluding remarks are then given.

PUB AND THE TOP-DOWN MODELLING APPROACH

Neither prediction in ungauged basins nor top-down modelling is new. Construction and application of regionalization techniques for systematic estimation of hydrological variables (primarily related to streamflow) at ungauged sites is, of course, a top-down modelling activity that many hydrologists were actively engaged upon long before the PUB Decade. Prediction in ungauged basins continues to be a key research activity. However, uncertainty in estimates at ungauged sites derived from physical catchment properties is still typically large, even for regions with relatively dense hydrometric networks, so there is no doubt that the PUB Decade is required. Consider, for illustrative purposes only, the time to peak, *Tp*, of a simple triangular unit hydrograph (UH) estimated from physical and hydroclimatological characteristics for UK catchments. (For systematic application of this triangular UH at ungauged sites, its peak flow and base-width are constrained to be simple functions of *Tp*.)

The regionalization equation for *Tp* currently widely-used in the UK is reported in the *Flood Estimation Handbook* (FEH, 1999) to have a standard error on *Tp* of about +85%/–46%. An equation for *Tp* published many years earlier, based on analysis of shorter records from fewer catchments and using different hydroclimatic descriptors, is reported to have a standard error of +48%/–32% (FEH, 1999). Consideration of how these equations and their uncertainties were derived suggests several reasons why, superficially at least, predictive ability for *Tp* appears to have worsened, but this observation should not be interpreted too negatively (Littlewood, 2004); further analysis is required. Nevertheless, it illustrates the problem that the uncertainty in *Tp* is large and, more importantly, that there is no clear evidence that progress is being made in terms of reducing predictive uncertainty on *Tp*. (Calver *et al.* (2004) outline recent and ongoing research towards next-generation approaches for modelling flood frequency in the UK.)

It is worth noting that if similar UH analyses were undertaken for regions with approximately the same range of hydroclimatic regimes as experienced in the UK, but where the hydrometric network densities were lower, the standard error on *Tp* for ungauged sites estimated in the same way would probably be larger than the +85%/–46% mentioned earlier. In regions where the hydroclimatic regime is less amenable to systematic estimation and application of *Tp*, the uncertainty would be expected to be higher still.

Estimation of *Tp* for ungauged UK catchments is a specific case of a general problem. The PUB Decade recognizes links between the uncertainty in an estimate of any one of many hydrological variables at an ungauged site and: (a) the quality and amount of data available in the region for the variable in question; and (b) the efficacy of the analytical techniques currently being applied to devise systematic regionalization schemes. Bearing in mind these points, an overarching aim of PUB is to reduce predictive uncertainty in estimation schemes for application in a wide range of hydro-climatic zones around the world.

Estimation of streamflow is a common requirement but there is an increasing need to estimate other hydrological variables at ungauged sites, e.g. sediment and nutrients (instantaneous fluxes and mass loads over time), and habitat variables. However, the estimation of flow at ungauged sites, from rainfall over the basin and physical catchment properties, remains a key issue. Estimates of flow are employed to assist with the design and safe operation of hydraulic structures (e.g. reservoir dam spillways). They are also used for many other aspects of river basin management, including assisting with equitable allocation of water resources and the setting of conditions stipulated in licences granted to abstract water from, or discharge (polluted) water to, rivers and other water bodies. This paper, therefore, will continue to focus on flow, though it is anticipated that advances will be made for other variables during the course of the PUB Decade.

Consider, first, the simple case of flow estimation at an ungauged site situated close to a gauged site. In a geologically and pedologically homogenous region where there is a high streamflow gauging station density, evapotranspiration is spatially quasi-uniform and flow regimes are largely unaffected by anthropogenic effects, a good estimate of streamflow at an ungauged site can often be obtained using flow measurements at a nearby upstream or downstream gauged site (making simple adjustments to take account of differences in catchment size and basin average rainfall). The distance between the ungauged and gauged sites should be small so that the catchment rainfalls are not too different. A separate adjustment might be necessary to account for any substantial tributary inflows between the gauged and ungauged sites. It might be possible to use measured flows from a nearby adjacent catchment on another river, but this is likely to give greater uncertainty than using local upstream or downstream flow data. The errors can become large if the gauged site is some distance from the ungauged site in question, not least because the temporal patterns of rainfall over the gauged and ungauged catchments may be quite different. An alternative, more general, approach (of greater interest here) is to use not only data from nearby gauged sites but data from all gauged catchments in a wider region (i.e. encompassing a range of catchment sizes, annual rainfalls, geology, land use, soils, slopes, etc.), and to seek a general relationship for estimating flow at ungauged (flow) sites from rainfall inputs and catchment characteristics.

For a region with a relatively dense raingauge network, a process-based rainfall–streamflow model can, in principle, estimate the flow at an ungauged site from measurements of the rain falling on the otherwise ungauged catchment. In practice, however, the complexity of process representation in the model is a key issue. It is useful to consider two modelling approaches defining the ends of a spectrum; "bottom-up" and "top-down". In its purest (unattainable) form, a bottom-up rainfall–streamflow model comprises representation of all the physical processes and pathways that affect molecules of water which, having fallen as rain, pass through, or evaporate from, a catchment. (For simplicity, other forms of precipitation, and physical processes at the sub-molecular scale, are ignored here.) Even if it were possible to construct such a computational catchment model it would be prohibitively costly and impractical to operate because of its need for vast amounts of data describing the temporal and spatial detail of rainfall, flora, fauna, soils, geology, land use, etc. (To state the rather obvious, if the flow at a specific ungauged site were required to be known it might be easier and less costly to measure it than resort to extreme bottom-up modelling.) Detailed measurements and modelling studies of within-catchment processes can certainly advance our understanding of water movement in the natural and built environment but the results from such studies are often not easily transferable to ungauged plots or to computer models of whole catchments.

At the other end of the modelling spectrum, a top-down catchment-scale rainfall–streamflow model, in its purest form, seeks only a mathematical relationship between spatially averaged basin rainfall and streamflow at the catchment outlet. It makes no attempt to represent the processes involved. A simple regression model for estimating monthly mean flow from monthly rainfall, for example, involves no representation of how the rain becomes streamflow. For this reason purely statistical models (e.g. simple regression and auto-regression models) are sometimes called "black box" models.

In practice, computational rainfall–streamflow models usually lie between the end-members described above but a given model may still be referred to loosely as either "top-down" or "bottom-up" depending on which half of the spectrum it is perceived to lie. A regionalization scheme involving unit hydrograph-based rainfall–streamflow modelling, e.g. using *Tp* as mentioned earlier, is an example of the top-down approach. There are many other discussions of top-down modelling in hydrology (e.g. Sivapalan *et al*., 2003b). Indeed, top-down models form a cornerstone of practical hydrology. A working-definition adopted by the TDWG is that:

> top-down models seek to explain, encapsulate understanding, and provide adequate predictive capability, using process conceptualization (representation) at a level of complexity appropriate to, but not usually exceeding: (a) that required to address the problem in question (Occam's Razor); or (b) that which is justifiable on the basis of information extractable from available observational data. Different models, or different levels of model complexity, may be required to address different problems.

Top-down, continuous simulation, rainfall–streamflow models tend to be "spatially lumped" and have a simple structure. Typically, they require only a few parameters to be estimated (calibrated) from time series of observed rainfall, streamflow and air temperature (or evapotranspiration) data, often with good accuracy and precision. A model closer to the bottom-up end of the modelling spectrum would prescribe a more detailed, spatially distributed, model structure on the premise that representation of all physical processes considered to be important is a prerequisite to achieving good model performance. However, many of the typically large number of parameters in such models are poorly defined conceptually at catchment-scale, and often they can be estimated only inaccurately and/or imprecisely using basin rainfall and streamflow.

The (relatively) few parameters of top-down models cannot generally be determined directly from sub-catchment-scale process experiments but they tend to be less uncertain statistically, when estimated from rainfall and streamflow data, than the parameters of structurally more complex, bottom-up, models. The top-down approach tends towards "parametrically parsimonious conceptual models" (PPCMs), while the bottom-up approach tends towards "parametrically generous conceptual models" (PGCMs) (Littlewood *et al*., 2003). Given the typically lower uncertainties associated with top-down rainfall–streamflow model parameters, useful statistical relationships between them and physical catchment attributes, e.g. slope, drainage density, land use, etc., are more likely than for parameters of bottom-up models. Top-down models are therefore likely to be more useful than bottom-up models for systematic estimation of flows at ungauged sites (regionalization).

PUB is an inclusive initiative, seeking to bring together those who are active in hydrological science and environmental management towards the goal of reducing predictive uncertainty for ungauged (or poorly gauged) basins. There is certainly a place within PUB for scientists whose primary aim is the better understanding of processes within catchments, leading to improved bottom-up models of those processes. However, given that hydrology, e.g. for water resources management, is essentially a practical subject requiring techniques that can be applied systematically and with demonstrable statistical performance (accuracy and precision) at catchment-scale, there is most certainly a place in PUB for top-down modelling. The TDWG provides a framework within PUB for top-down modellers, and welcomes dialogue with all other PUB WGs.

TDWG REPRESENTATION AT CONFERENCES AND WORKSHOPS (TO APRIL 2005)

The period to April 2005 witnessed intensive TDWG activity for the organization of, and participation in, workshops and sessions at national and international meetings. Slideshow presentations with a TDWG component given by the authors at several of the following events can be seen at the TDWG website introduced in the next section.

IUGG/IAHS Assembly, June 2003 At this meeting (Sapporo, Japan) two presentations gave examples of some of the approaches intended to be used within the TDWG. The first presentation described how the top-down approach could be used within PUB, with some examples for catchments in the UK. The second presentation described work being undertaken in Australia on estimation of the unit hydrograph and regionalization of the runoff coefficient and flow duration curve, and the potential of these approaches for parameterizing models at ungauged sites.

French Workshop, November 2003 A workshop "Prediction in Ungauged Basins: Space Data and Multiple Scales in Hydrology" was held in Paris, 17–19 November, 2003. A presentation was made on the use of unit hydrographs for regionalization, followed by an introduction to the TDWG.

Australia–Japan PUB Workshop, February 2004 A joint Australia-Japan Workshop on PUB, held at the University of Western Australia 2–5 February 2004, brought together nearly 100 researchers, practitioners and international scientists from a range of disciplines to discuss the problems encountered when making predictions in ungauged basins. As a contribution to this workshop, a presentation was made on behalf of the TDWG (Post *et al*., 2005). The goals of the TDWG and progress towards achieving those goals to that time were summarized under four headings: (1) determine what new insights can be obtained from existing data sets; (2) assess the predictive uncertainty in the current generation of hydrological models; (3) improve the current generation of hydrological models; and (4) create a new generation of hydrological models.

iEMSs2004, June 2004 A session "Modelling Hydrological Responses in Ungauged Catchments" was organized by the authors as part of the 2004 biennial conference of the International Environmental Modelling and Software Society (iEMSs). The session comprised 18 papers by authors from 10 countries (Australia, Bulgaria, France, Germany, Italy, Lebanon, Luxembourg, Taiwan, United Kingdom and United States). Each of the published 18 papers was concerned with generic and/or specific modelling issues of direct relevance to PUB. In the following brief survey of the 18 papers (a thorough review is beyond the scope of this paper) the papers are grouped for convenience.

Generic top-down modelling issues for the PUB Decade (including aspects of uncertainty) were dealt with by Croke & Norton (2004), Littlewood (2004), McIntyre *et al.* (2004) and Young & Romanowicz (2004). Facets of traditional and possible new approaches to regionalization of rainfall–streamflow model parameters with respect to physical catchment descriptors were covered by Hristov *et al.* (2004), Post (2004), Spate *et al.* (2004) and Young & Reynard (2004) (with example applications in most cases). In this same group, Calver *et al.* (2004) and Aronica & Candela (2004) paid particular attention to regionalization of flood frequency in the UK and Sicily respectively. Another group of papers, by Boyle *et al.* (2004), Drogue *et al.* (2004), Hreiche *et al.* (2004), Maréchal & Holman (2004) and Yu *et al.* (2004), were concerned with water quantity modelling in specific catchments. Three papers, by Candela *et al.* (2004), Lu *et al.* (2004) and Romanowicz *et al.* (2004), were more concerned with water quality (nutrients, sediment and chlorophyll-*a*, respectively).

PUB-MOPEX Workshop, July 2004 At the PUB-MOPEX Workshop (http://www.cemagref.fr/Informations/Actualites/colloque/Mopexweb/MOPEXParisWorkshop.htm), held in Paris, 1–3 July 2004, the TDWG was introduced (Workshop session 5) and results from application of the PC-IHACRES (Identification of unit Hydrographs and Component Flows from Rainfall, Evaporation and Streamflow data.) v1.02 package (Littlewood *et al.*, 1997) to three of the rainfall–streamflow data sets prepared for the Workshop were presented (Workshop session 2).

IUFRO Forest Hydrology Working Group workshop, July 2004 The objective of this meeting, organized by the International Union of Forest Research Organizations (IUFRO) Forest Hydrology Working Group, was to facilitate the exchange of research on fundamental and applied aspects of catchment processes in humid forest catchments of Asia. A TDWG presentation outlined PUB in relation to the warm-humid region of Asia (Croke *et al.*, 2004).

SIMMOD 2005, Bangkok, 17–19 January 2005 The purpose of the International Conference on Simulation and Modelling 2005 was to encourage the use of models in public and private sector decision-making in Thailand, and in southeast Asia generally. During the general hydrology session a presentation on the PUB initiative and the TDWG was given with an aim of extending the focus of the Group into other countries in southeast Asia.

Japanese PUB workshop, January 2005 This workshop focused on the use of land-surface models (LSMs) in hydrology. A presentation was given on some of the planned activities of the TDWG. This included work on catchment classification, use of data analysis (including spectral analysis and data mining tools), and the development of, and access to, catchment data sets. Some initial ideas of how LSMs might be used by top-down modelling approaches as well as application of the top-down philosophy to LSMs were discussed. This included using LSMs to provide information on spatial variability within catchments and using top-down models to address the issue of stepping from the point-scale, where LSMs are based, to the catchment-scale.

MODSIM 2005 During the period covered by this article a special session was being organized by the TDWG for the MODSIM 2005 conference, Melbourne, Australia 12–15 December 2005. The main planning focus of this session was the use of the top-down modelling approach in the context of PUB, and papers discussing the development of new models, testing of existing models as well as data analysis (e.g. data mining) and regionalization techniques were encouraged. However, field process study contributions that inform the structure of catchment-scale models, and developments in data sets (e.g. remote sensing), were also welcome.

IAHS Assembly, April 2005 The end of the period covered by this paper was marked by the VIIth IAHS Assembly held at Foz do Iguaçu, Brazil, at which a TDWG presentation was made in S#7-7 (forming the basis of this paper).

TDWG WEBSITE

The TDWG website (http://www.stars.net.au/tdwg/?welcome) became operational in November 2004. Links to and from the IAHS and PUB websites are in place. The welcome page (Fig. 1) indicates its contents. It already provides a good range of information, e.g. Newsletters #1 (January 2004), #2 (October 2004) and #3 (August 2005), and will continue to be developed as the TDWG evolves.

As a framework within the larger PUB framework, a major aim of the TDWG, and therefore its website, is to facilitate the exchange of ideas towards the formulation of top-down modelling projects that will contribute to the PUB Decade. Building upon earlier work on relevant modelling techniques and the estimation of streamflow in ungauged catchments (regionalization), a sub-group of the TDWG devised the INTRAPUB project. An outline of INTRAPUB is available from the "Projects" page of the TDWG

Fig. 1 The TDWG website.

website and is described in a little more detail in the next section. Other items and ideas, ranging from members seeking collaborators to details of completed projects, will be added to the Projects webpage as they are made available by Group members.

THE INTRAPUB PROJECT

TDWG participants from the Centre for Ecology and Hydrology (UK), Lancaster University (UK), Cemagref (France), the Australian National University, and CSIRO (Land and Water) (Australia), devised the INTRAPUB project (Information TRAnsfer for Prediction in Ungauged Basins). It will be concerned with "hybrid conceptual-metric" (Wheater *et al*., 1993) models and a "Data-Based Mechanistic" (DBM) modelling approach (e.g. Young, 2003, Young & Romanowizc, 2004) that focuses on the statistical identification and estimation of top-down models from information available in hydrological time-series. It will be directed at characterization of whole flow regimes, rather than low flows or high flows separately, and will consider ways in which uncertainties associated with the estimation of DBM models should be handled in regionalization analysis.

Employing the unit hydrograph-based IHACRES modelling approach (Jakeman *et al*., 1990, Littlewood & Jakeman, 1994), later work, e.g. by Sefton & Howarth (1998), Post *et al*. (1998) and Post & Jakeman (1999), suggested regionalization schemes for simulating continuous streamflow. Littlewood (2003, 2004) and Young & Romanowicz (2004) discuss some possible improvements to the rainfall–streamflow modelling that underpins the suggested regionalization schemes mentioned earlier. Furthermore, several developments are also helping to create good prospects for advancing regionalization using the IHACRES approach: the development of next-generation software (Croke *et al*., 2005); alternative non-linear module structures for estimating effective rainfall (Ye *et al*., 1997; Croke & Jakeman, 2004); and a technique for deriving an average event unit hydrograph for ephemeral, quick-flow dominated, catchments solely from streamflow data (Croke, 2005). The proposed INTRAPUB project will build upon all of the aforementioned work, using the full power of the DBM modelling approach.

A by-product of IHACRES modelling is often the separation of modelled streamflow hydrographs to give dominant quick and slow response flow components that have characteristic decay times. Subject to the additional availability of suitable water quality data sets, INTRAPUB will investigate further the utility of this hydrograph separation for understanding catchment-scale streamflow–generation processes. Concurrent investigation of rainfall–streamflow dynamic behaviour and streamflow-tracer concentration dynamics using DBM modelling techniques may help point the way towards improving the representation of processes within the IHACRES suite of models.

CLOSING REMARKS

An underlying principle adopted during the initial development phase of the TDWG has been to establish a Working Group infrastructure that helps to achieve the aims and objectives of the wider PUB initiative. Without being too prescriptive (in the interests of capitalizing on the enthusiasm and initiative of participants), the TDWG aims to facilitate the sharing of information and encourage dialogue towards the formulation of PUB-related top-down modelling projects. The TDWG framework has been created for research hydrologists to use as they wish. The authors would therefore welcome ideas for TDWG activities and projects, particularly from individuals or small groups who see the benefit of the Group for helping with the development and dissemination of their own top-down modelling ideas and projects within the context of the PUB Decade. Subject to a degree of editorial control, TDWG participants are invited to provide information for the Projects page of the TDWG website.

This paper has presented a working definition of a top-down model and discussed some of the broad issues that distinguish top-down from bottom-up modelling. It is anticipated that the INTRAPUB project, outlined in the paper, will be one of several ideas/projects led by TDWG participants.

The paper has outlined TDWG representation at PUB (and other) meetings and workshops. As the PUB Decade unfolds further it is anticipated that, where it is to mutual advantage, there will an increase in dialogue between the TDWG and other PUB Working Groups. Indeed, some members of the TDWG are members of other PUB WGs (e.g. the PUB-MOPEX and the Uncertainty Estimation for Hydrological Modelling WGs, http://cee.uiuc.edu/research/pub/ListWG.asp), which can only help with future interactions between the WGs. The TDWG looks forward to further interactions with these and other WGs.

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