Conclusions from the Córdoba meeting on IAHS next decade

Next Scientific Decade 2023-2033

Introduction

The aim with launching a joint research topic and organising a Scientific Decade is to accelerate scientific achievements in a hydrological field by stimulating engagement, synthesis work and scientific sharing across numerous research groups worldwide. IAHS has run two successful scientific decades, which fostered knowledge accumulation and streamlined global research efforts, regarding:

2003-2012: Predictions in Ungauged Basins (PUB)

2013–2022: Change in hydrology and society — Everything Flows (Panta Rhei)

It has been recognised that the topic of a decade needs to be broad enough to engage the wider hydrological community but narrow enough for concerted actions. It must be timely and relevant to generate interest and make a difference. *The first decade* tackled the problem with data scarcity and transfer of hydrological knowledge in space and time, while *the second decade* addressed the concept of change and human alterations/co-evolution with the hydrological cycle. *The third decade* will be ***solution oriented*** and search to find a scientific basis for understanding and reducing the local effects from the rising global water crisis in the Anthropocene. This was concluded from the IAHS discussions (see Appendix), which expressed readiness to make a difference in realising global development goals for a sustainable Planet Earth. The present concept note was consolidated from reflective and creative input by the IAHS community in: the Cordoba workshop (50 pers) during three days; on-line meetings (100 pers) in three time-zones; posts in a forum (40) of the IAHS website.

Unsolved Problems in Hydrology (UPH)

In the middle of the last Scientific Decade, the IAHS community identified 23 unsolved problems (Blöschl et al., 2019) with scientific questions, which could be categorised into seven types, all with relevance for various subdisciplines in hydrology (Fig. 1). It is important that the new decade takes stock of these identified scientific problems and covers all categories of questions identified by the community to make a holistic synthesis of issues.

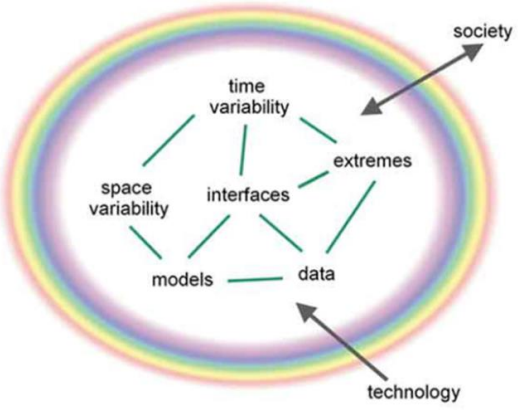

Figure 1: UPH categories in hydrological synthesis of subdisciplines.

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WHY another scientific decade?

The Earth is facing severe problems due to climate change, globalisation, and population growth – the Anthropocene has put the Planet into an emergency state, where impacts on the water cycle is accelerating the crisis; the freshwater often varies being too much, too little or too dirty for sustainable development. Hydrological knowledge is needed more than ever, but so far, water issues are spread over many actors and organisations. Likewise, scientific knowledge on resilience and water security is fragmented. There is a substantial lack of synthesis and easily digested scientific messages across disciplines and from scientists to practitioners. Hence, there is a large need for concerted actions from the hydrological research community to provide water-centric decision support. The next decade must thus identify local water problems in holistic/system analysis (i.e. linking the scales and connecting the dots), it must be bold and push boundaries to make an impact, be of global and local relevance, connect people and provide synthesis to answer the needs of society for sustainable development, safety and security. Concerted actions by hydrological scientists providing water knowledge in engagement with other disciplines and stakeholders are essential for solving environmental and societal issues, which all depend on water.

To sum up, there is an urgency for the new initiative on a *Science for Water Solutions Decade*.

WHAT should the Scientific Decade contribute?

The Scientific Decade will consolidate the hydrological sciences community, give visibility and set the trends and agenda for water research. It will focus on synthesis work, comparative analysis and transferability of knowledge. The new decade will provide understanding of water components in environmental and societal challenges, along with the potential impact of measures for resilience or restoration to reach sustainability goals at global and local scale. Policy-makers search for holistic systems thinking of solutions to avoid the water crisis in various nexus (e.g. food security, energy supply, ecosystem health, flood management, transport and navigation, sanitation facilities, drinking sources, industrial usage, mental health and recreation). In water scarcity there is a need for integrated solutions and informed decisions for fairness and sustainability. Water security needs early warning systems, climate indices, and design values from predictions at local and regional scales. The water system on Earth is one unit with complex interactions, which need to be well understood for sustainable development. Hence, the new decade also needs to encompass capacity development and communication skills among hydrological scientists, to engage across disciplines and with decision-makers and eventually to empower operational hydrologists at various levels and at every site on Earth.

The new decade will profit from current technical achievements with artificial intelligence, big data and open science for innovations and evaluations using many sources of information in quality assurance of findings. It will liaise with the rising movements in citizen science, new sensors and observations to increase hydrological process understanding and facilitate predictions under novel spatial and temporal conditions. The new decade will

especially highlight solutions and quantify remedial effects from e.g. constructions of grey, green, and blue infrastructure, modified water operations, agricultural practices or spatial planning. Experience from one site may be relevant for meeting challenges in another site under new conditions (i.e. replacing time with space studies). For instance, under climate change new sites in the northern hemisphere need to learn how to handle drought and benefit from participatory processes, while sites in the south need to consider impact-based forecasts and flood warning systems despite data scarcity; here North and South can learn from each other.

Last but not least, the decade will inspire and stimulate hydrological scientists to contribute more and better together than individually – hence, inclusiveness is key for success.

HOW will it be organised?

To facilitate leadership and continuation throughout the decade, the next scientific decade will be organised according to a classical Project Management structure with defined Work clusters of Actions for the collaborative work at multi-levels (Fig. 2). It will be fully open to new initiatives suggested by any IAHS member and such actions will also be open for participation by anyone who wishes to contribute. Inclusiveness is one of IAHS core values (https://iahs.info/About-IAHS.do) and so is active engagement, transparency and personal responsibility in the collaborative process. IAHS recognise that equality and diversity is required for scientific progress and embrace integrity, trust, and respect as guarantee for the openness and creativity that is needed to accelerate science.

The new decade strives for tangible results and transparency, and therefore, the work will be reported regularly and progress will be followed and monitored by the *Decadal Management team* so that they can help the Work-cluster leaders with engagement, competences and communication activities, as well as finding synergies and stakeholders or data sources for the various actions. The IAHS communication team will provide information tools, such as the IAHS web site, joint publications, social media channels and the Digital Water Globe. A *Steering Committee* will help engage with other global communities (e.g. in the UN-family), coordinate with other IAHS activities and give visibility to the on-going work and findings. The Steering Committee will also assist in any collaborative disagreements and encourage open science, fair data, EDI, publications, policy briefs and citations.

Work-cluster leaders will identify and approve tasks and actions needed to advance their sub-topic of the Scientific Decade, they will follow up on progress and initiate actions, such as workshops, outreach activities, collaborative publications or projects (e.g. comparative studies or ensemble modelling). They will help and guide the appointed *Action leaders*, who are responsible for coordinating such specific activities that aim to accelerate knowledge accumulation from the scientific community, and hence, progress within the work clusters.

The actions are fully open to initiatives from the community and serve as a platform for testing ideas in a cooperative manner. Leading such an action also offers an opportunity for scientists to develop their leadership skills with mentoring from senior scientific leaders.

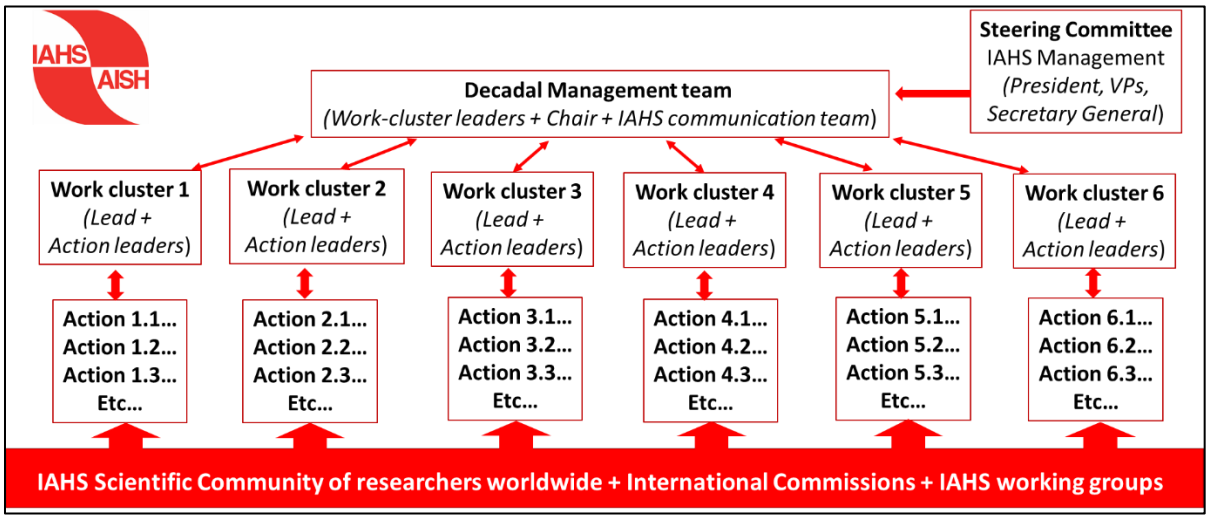


Figure 2: Schematic structure of the organisation to manage the Next Scientific Decade.

IAHS is not a research council or a donor, but a charity who consolidate voluntary work and provide grants for networking and scientific publications. Therefore, the activities of the decade need to be based on already financed projects or institutional work and thus rely on current research trends (often underpinned by political ambitions). However, as IAHS offers the basis for networking and participating in synthesis or review publications, it can also be an opportunity for attracting external funding and thus create projects in line with the ambitions of the New Decade. The set-up will be agile with learning in feedback loops over time to allow co-evolution during the decade between progress in hydrological sciences and new challenges appearing in society, environment, or other disciplines. The decade supports education and training and will become a fertile breeding ground for continuously evolving new actions in each work cluster below.

Content in Work Clusters

The new decade will boost the scientific community by stimulating actions in six interlinked work clusters to underpin solutions for the water crisis, leaving no catchment or hydrologist behind.

Work Cluster 1: Global and local hydrological intelligence (Glocal)

Aim: to accelerate hydrological understanding of hydrological processes at local and global scale, how they interact and affect water resources.

Description: The observed diversity in hydrology across the globe is still not understood using current conceptualisation and data sources. Many observed phenomena and discrepancy between scales are yet not explained (e.g. impacts and feedbacks to climate or vegetation changes), hence we encourage further attention to system analysis, connectivity, evolutionary loops, human alterations and complexities such as non-linearity, non-stationarity, tipping points, system memory and trajectory. Solutions to handle the water crisis must be underpinned by knowledge of current water systems behaviour to ensure

sustainability by allocating the right measures at the right time. The research could be supported by methods in statistics, machine learning/AI or process-based modelling and utilise all kinds of data (in-situ measurements, remote sensing, citizen science). Comparative studies are encouraged and alignment with open science for data sharing across scales.

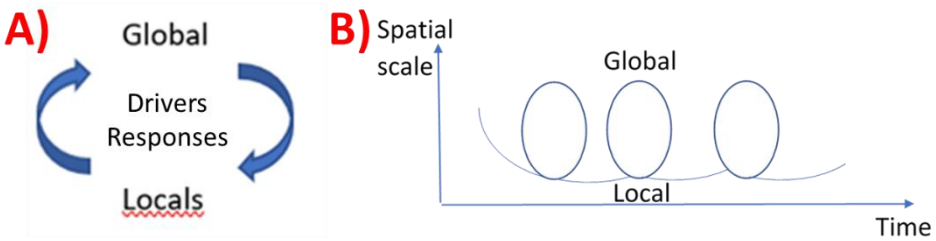


Figure 4: Interactions between global and local scales are: A) both top-down and bottom-up, and B) fluctuating and co-evolving over time.

Examples of potential research questions:

- What is the robustness in water predictions for each catchment across the globe?'
- How large are the changes in hydrological impact/feedback from climate change?
- What influence has local morphology on hydro-dynamics?
- Which local thresholds and feedback cause global transitions and tipping points?
- How to understand surface-groundwater interactions in various parts of the world?
- How does climate change impact water quality?
- How do micro-climates impact large scale water availability?
- Why do global models fail at the local scale?
- How to improve down-scaling approaches for local water managers?

Examples of results and outcomes:

- New understanding of interlinked hydrological cycles and resource variability.
- Peer-reviewed publications (methods, models, assessments).
- *Vision*: Hydrology is recognised as a core science in each sustainable development goal.

Work Cluster 2: Water security

Aim: to manage current crises and to avoid or reduce future water crisis.

Description: Water scarcity, quality deterioration, floods and hazards should be foreseen and measures should be taken so that their effects are minimised. Here we address all dimensions of water issues, such as undesired quantity and quality, extremes, availability vs. demands/needs, transboundary waters, compound transport, cascading effects. Similarly, we address all sorts of innovative solutions and make comparative studies of already implemented solutions, and predict effects of planned ones, by e.g. modelling or replacing time with place, when suggesting methods to avoid problems in the future. Many countries nowadays endeavour green transition of society, with focus on nature-based solutions and fossil free sectors. The nexus between water and various sectors are crucial to find holistic solutions, as well as between society and ecology to ensure sustainable development. For smooth implementation of solutions and long-term maintenance, we need efficient policy

processes across sectors with shared frameworks to evaluate impact on economy, justice, fairness and equality. Hence, interdisciplinary studies are of major importance for this WP.

Examples of potential research questions:

- Where across the globe do we have evidence of intensifications of water extremes?
- How do nature-based solutions influence the water cycle?
- What criteria should be used for choosing measures to enhance water security?
- When will nature-based solutions impact resilience, in space and time?
- How to make best use of forecasting for resilience?
- How to prepare urban systems for extremes?
- How to best involve social scientists in problem solving?

Examples of results and outcomes:

- New understanding of solutions impacts and optimal engineering.
- Goal oriented peer-reviewed publications (methods, models, assessments).
- *Vision*: Water security is seen as a human right.

Work Cluster 3: Empowering people locally

Aim: to build capacity in local societies and learn from local experience for solutions acceptability, affordability, accessibility and equitability.

Description: Water issues may arise from global drivers and policy decisions (e.g. climate change, upstream management changes) but often need local solutions by local people, who then need to be knowledgeable in their decision-making both for adaptation and for mitigation. Indigenous knowledge may be applicable and help with solutions, and so do new scientific findings with evidence-based records, which may be well suited also for new locations. Here we appreciate citizen science in its full spectrum from data sourcing, understanding, engagement, and participatory processes to create learning societies between hydrological scientists and stakeholders. We foresee social innovations, capacity development and entrepreneurship in practical applications but also advancements within socio-hydrology for deeper understanding of co-evolution between hydrology and society.

Examples of potential research questions:

- What are the major local hydrological challenges across the world?
- What are the prerequisites for local knowledge-brokerage of solutions globally?
- How has hydrology and society co-developed in various parts of the globe?
- Which methods are best when training the trainers?
- What are stakeholder needs?
- How to use local/indigenous knowledge in models and systems understanding?
- How to strengthen citizen science?

Examples of results and outcomes:

- Evidence-based applications and case-studies.
- Interdisciplinary peer-reviewed publications (applied showcases, new theories)
- *Vision*: Local ownership for finding, implementing and maintaining water solutions.

Work Cluster 4: Hydrological communication and engagement

Aim: to reinforce communication skills and engage with the general public and citizens.

Description: Fact-resistance is currently spreading among citizens and politicians; thus, scientists need to better explain the value of scientific evidence and translate science into understandable knowledge for comprehensiveness. Here we recognise the increasing value for decision-making when going from simple data transfer, through interactive information services, towards networking in knowledge-action systems. The world searches for means to translate scientific results into wisdom, but challenges are growing with the information overload. There is an urgent need for ways to consolidate key-messages (keeping credibility and cautions), data tailoring procedures for specific users, and facilitation of engaging dialogues with specific target groups. Hydrological scientists need training in transparency and co-creation to increase user up-take of e.g. water-information and communication technology. Moreover, new methods in science communication using art, story-telling and creative events, need scientific evaluation of impact on citizens' attitudes. Developing new avenues in education for consciousness may lead to water resilience in a changing world.

Examples of potential research questions:

- Can hydrological scientists agree on 'core messages' to the general public (as IPCC)?
- What/How does various user groups need information from hydrological scientists?
- Which communication methods are available and most suitable at various occasions?
- What are the most effective ways to communicate with different stakeholder groups?
- Which are the most effective co-creation methods and visualisation tools?
- What should be in the 'hydrologists guide to communication'?
- How do we transform the education of hydrology and include voices from underrepresented areas?

Examples of results and outcomes:

- New tools for engaging with scientific results and methods for packaging information.
- Evidence-based peer-reviewed publications (applied frameworks, guidelines, services)
- *Vision*: Better equipped hydrological scientists realising science-based water solutions.

Work Cluster 5: Unravelling the unknowns

Aim: to anticipate the unpredictable and move beyond current state-of-the-art concepts.

Description: Hydrological sciences tend to become repetitive and stuck in validation of previous findings or constrained by data limitations and unspecified boundary conditions. Experiments often use similar underlying assumptions and are thus not independent and complex system analysis is often difficult to evaluate due to lack of documentation. Here we stimulate a critical view on hydrological research, which is by nature a pragmatic science but needs to be elated by epistemic actions for more radical progress. Discussions about the nature of knowledge are essential for scientific acceleration and here we foresee unexpected results from new theories, brave experiments (which failed) and progress from

mistakes. Courage and failure should be appreciated and published in a learning community, as sharing unsuccessful efforts adjusts future attempts and sharpens creativity.

Examples of potential research questions:

- Where do we have hydrological "black swans" (e.g. unseen events)?
- How extreme are the extremes?
- Do we have examples of implemented solutions that did not have desired effect?
- How to prepare water managers for the unknowns?
- How to model tipping points, non-linearity, non-stationarity, compound events?
- How to quantify models predictive power vs total uncertainty of results?
- Where are the monsters in hydrology? Processes we cannot model and human reasons for lack of progress.

Examples of results and outcomes:

- New research questions and emerging scientific fields in hydrology.
- Peer-reviewed publications (innovative data analysis, bold experiments, opinions).
- *Vision*: Paradigm shifts in hydrological sciences.

Work Cluster 6: Pushing water frontiers

Aim: in-depth partnership with other scientific communities for convergence on solutions.

Description: Even though hydrology is central for solving the water crisis, it needs to be considered in the light of other essential components influencing Planetary health. Traditionally, hydrological sciences work closely with other geosciences or engineering when striving for coordinated and coherent whole (i.e. interdisciplinarity). However, here we go beyond that and explore if multidisciplinary research could be a gamechanger, by engaging with disciplines such as economy, biology, psychology, political sciences, and humanities. The challenge is then viewing the water crisis from the viewpoint of the different disciplines and collaboratively developing new theories and methods by integrating the current ones from each faculty into completely new solutions. Transdisciplinary work starts with a common learning process for everyone involved, also including non-academic stakeholders. This process is normally time-consuming and therefore very suitable for a decadal initiative.

Examples of potential research questions:

- How to define 'holistic water management'?
- How to link ecology, biogeochemistry, humans and hydrology?
- What are the cascading effects: hydrology-water quality-ecosystem stability-human health?
- What influence does the global economy have on local water demands and availability?
- How to analyse water impact on each of the UN SDG subgoals and criteria?
- Is there a way back from tipping points caused by globalisation?
- What characterises resilient catchments?
- How can we implement true inclusivity to access hydrology for all (open science)?

Examples of results and outcomes:

- Understanding complex global and local interactions across scientific disciplines.
- Transdisciplinary peer-reviewed publications (Earth system analysis including societal transformation, theoretical frameworks).
- *Vision*: Holistic systems understanding of Planet Earth under Anthropocene.

Way forward

A smaller team of writers (15 persons) will be invited to draft a Concept note, based on the documented outcome of the Córdoba meeting. The writing team should reflect active engagement in organising the process and represent different parts of IAHS. The following persons are invited (countries):

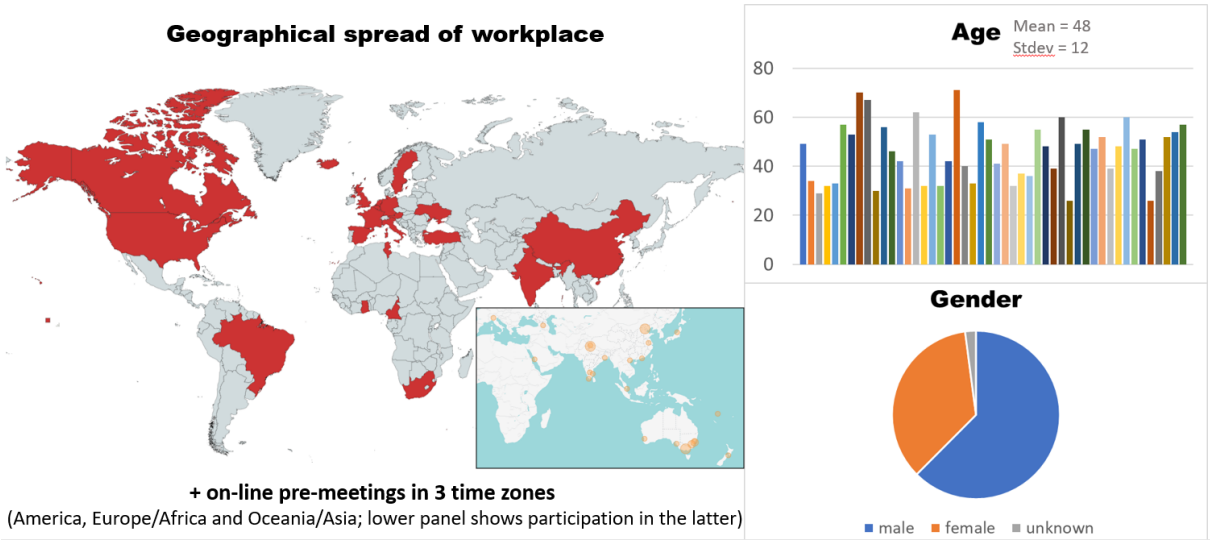
- *the IAHS Officers and Córdoba workshop organisers*: Berit Arheimer (SE), Christophe Cudennec (FR), Guenter Blöschl (AT), Salvatore Grimaldi (IT), Maria José de Polo (SP)
- *On-line conveners or co-conveners*: Barry Cloke (AU), Chris Leong (JP/FIJI), Stacey Archfields (USA), Giova Mosquera (ECUA), Melody Sandells (UK), Jean-Marie Kileshye Onema (SA)
- *The Early Career Committee*: Moctar Dembélé (GH), Bertil Nlend (CMRN)
- *Early career opinion paper in HSJ (lead author)*: Tessa van Hateren (LU)
- *South America initiative*: Pedro Chaffe (BR)

The drafted Concept note will be available at the IAHS website for comments from the community in the Forum from 15 March to 15 April. A one-day workshop will be arranged in Vienna on 29 April (after EGU) at the Vienna Technical University, to further elaborate on actions and content in the next Decade. The time table for the process is available and updated at https://iahs.info/Initiatives/Topic-for-the-Next-IAHS-decade.do.

Eventually, the outcomes of the Córdoba meeting and the final Concept note will be the basis for an Opinion paper in HSJ, to which all contributors (in-person or online) will be offered to co-author.

APPENDIX

Some metrics on diversity among the scientists participating at the workshop in Córdoba when collecting input to this concept note during three days, 1-3 February 2023:



+ on-line pre-meetings in 3 time zones
(America, Europe/Africa and Oceania/Asia; lower panel shows participation in the latter)

The work was organised in round-table discussions (8 persons per Table) steered by answering the questions below and reporting in Plenum, followed by open discussions:

Collecting input to the Concept Note

Input for Plenum 1 Feb at 14 hrs CET:

1. What defines a successful Scientific Decade?
2. What do we want to achieve in the long-term and short-term, respectively?

WHY?

Input for Plenum 2 Feb at 10 hrs CET:

3. What are the current drivers/trends in Fundamental and Applied Research?
4. What are the societal needs of scientific results?
5. Where to position IAHS? (vs other global scientific communities)

WHAT?

Input for Plenum 2 Feb at 14 hrs CET:

6. Brainstorm potential topics (and sub-topics/science questions) of the Next decade!
7. Identify short and catchy names
8. Make a brief SWOT analysis for each one (Strengths, Weaknesses, Opportunities, Threats)

Input for Plenum 3 Feb at 10 hrs CET:

9. Identify sub-topics, science questions and Results of the Next Scientific Decade!
10. Suggest an organisational structure and communication/work activities (based on previous experiences)

HOW?