2nd Global Workshop on
Dynamic Water resources Assessment Tool (DWAT)

FINAL REPORT

SEOUL, REPUBLIC OF KOREA

7 to 9 May 2019

1. Opening Session

1.1 At the kind invitation of the Ministry of Environment, Republic of Korea, and with the financial support of the Republic of Korea, the 2nd Global Workshop on the Dynamic Water resources Assessment Tool (DWAT) was held in Seoul, Republic of Korea, from 7 to 9 May 2019.

1.2 The meeting was opened at 14:00 on Tuesday 7 May 2019 at the Han River Flood Control Office, Seoul, Republic of Korea. The purpose of the workshop was to verify the performance of DWAT and to receive feedback from the experts from all WMO Regions on the newest version of the DWAT User's Manual and its software. The workshop will also discuss potential future improvements to DWAT and will document its related conclusions and recommendations.

1.3 Mr Jaeheyon Park, Director General of the Han River Flood Control Office, Ministry of the Environment, Republic of Korea, and Hydrological Adviser to the Permanent Representative of the Republic of Korea with WMO, welcomed participants to the Han River Flood Control Office and Seoul. He underlined the potential heightened variability in the availability of freshwater resources due to climate change, hence the challenges posed when undertaking a water resources assessment. In order to enhance the capacities in water resources management, Republic of Korea has cooperated with WMO in the framework of the RA II Working Group on Hydrological Services and the WMO Commission for Hydrology to develop and distribute at the international level the DWAT. Finally, he wished participants a fruitful workshop.

1.4 Dr Paul Pilon, Chief of Hydrological Forecasting and Water Resources Division, WMO Secretariat, thanked Mr Park, Director General of the Han River Flood Control Office, and welcomed the participants from the Republic of Korea and abroad on behalf of Prof. Petteri Taalas, Secretary General of WMO, to the 2nd Global Workshop on the DWAT. He expressed particular appreciation to the role of the Republic of Korea in developing the DWAT and in helping to organize and finance the Workshop. Dr Pilon also brought forward the welcome of Mr Harry Lins, President of the WMO Commission for Hydrology, who could not attend due to health reasons. Dr Pilon underlined the importance of having a clear picture on the status and outlook of available water resources, hence the importance of a tool such as the DWAT being made freely available to the international community. He emphasized that this 2nd Workshop provided a second opportunity to have international experts, who have reviewed the DWAT, and the same software developers to sit around the same table and exchange views on the software's usability and performance. At the same time, this Workshop will provide an opportunity for other participants to have direct hands-on experience on the functionalities of the DWAT and to share their views on the software as well.

2. Introduction of Participants and workshop programme

2.1. Participants introduced themselves. 11 participants from 5 countries and two WMO staff attended the Workshop, with around half of the participants being from the Republic of Korea. Five of the international participants were invited as experts from different WMO Regional Associations, namely Region I (Africa), II (Asia), III (South America), IV (North America and Caribbean), V (Pacific) and VI (Europe). Due to last minute issues such as health and travel, a few experts invited from Region I (Africa) and Region VI (Europe) could not attend. The List of Participants is provided in Annex 1.

2.2. After the presentation on the Workshop programme by Dr Hwirin Kim (see Annex 2), Dr Hyeonjun Kim provided a presentation on advances and modifications made to DWAT following the 1st Global Workshop. The modifications made were numerous, with the main ones captured in his presentation, which is available on the website https://public.wmo.int/en/water/dynamic-water-resources-assessment-tool. The participants were pleased with the summary of items presented and looked forward to the opportunity of expressing their views on these and other aspects of DWAT, which were to be made later during the Workshop programme.

2.3. Dr Hyeonjun Kim from KICT illustrated the advances made in the DWAT since the 1st Global Workshop. These changes were summarized in document to assist in responding to the CHy Peer-review Report. This document was reviewed item-by-item and was revised during the meeting. Participants were also informed about the development of 7 tutorial video clips of 3 minutes duration to assist potential users in understanding various aspects of DWAT. It was noted that the clips might require some modificaitons and would be made available through the DWAT website.

2.4. Following an overview of the advances and modifications to DWAT, the experts provided presentations on the results stemming from the application of the modified DWAT to their basins. This was followed by an interactive hands-on session of adjusting the DWAT applications and an assessment of results.

3. Results of DWAT applications

3.1. Prior to the Workshop, the experts were provided the DWAT software. The DWAT User's Manual v1.1 was distributed at the opening of the workshop. The objective was to have the experts test the modified DWAT on their local basins, as well as also assessing model performance by comparing output with observed data. This would also allow an opportunity for experts to assess modifications that had been made to the software since the 1st Global Workshop. The experts presented their results and experiences in running the modified version of DWAT, with these being captured in the following paragraphs. All presentations made during the workshop are available on the DWAT website[1].

3.2. Mr Bikash Pradhan and Mr Sangay Tenzin (Bhutan, RA II) presented the results of the model application. They also described the application of an Auto-Regressive Integrated Moving Average (ARIMA) model to "update" or correct the DWAT output. This greatly improved the matching of observed and simulated DWAT results. Their conclusions were that the DWAT simulation, provided it was corrected through application of the ARIMA method, resulted in a good performance under the specific runoff conditions of Bhutan, allowing them to capture trends and peak flows. They also expressed that the model could also be used to provide 3-day forecasts. Mr Bikash's report on the application of the model can be found in Annex 3.

3.3. Mr Marcelo Uriburu Quirno (Argentina, RA III) provided a case study based on the basin of Rio Burrumayo in Argentina. His results indicated that the numerical results resulting from a semi-distributed scheme were only marginally improved over the old DWAT version. However, usability of the interface has greatly improved. He also noted that the results from a lumped scheme (adopted for the new version of DWAT in his case study) performed better than the semi-distributed scheme, which had been used in the 1st DWAT workshop. He also noted that manual calibration provided a much better representation of base flows than automatic calibration, while the overall statistics from the automatic calibration scored higher. His report is available in Annex 4.

[1] The DWAT website is: https://public.wmo.int/en/water/dynamic-water-resources-assessment-tool

3.4. Mr Geoffrey Marshall (Jamaica, RA IV) focused his efforts mainly on the use of DWAT in basins having limited availability of data. The existing rainfall network was deemed not to have a sufficient network to capture all significant rainfall events, hence there were notable discrepancies between the model outputs and the observed data. He appreciated the improvement in terms of usability of the DWAT software since the 1st Global Workshop in Bhutan. Mr Marshall also provided a report, which can be found as Annex 5.

3.5. Mr John Fenwick (New Zealand, RA V) provided a presentation on his case study, characterized by sparse data in a mountainous catchment (Jollie) with high rainfall gradients. Mr Fenwick noted that a meteorological station was located outside the basin and over a mountaineous divide and at a low elevation compared wit the upland portion of the basin. As well there was the possibility of snow processes occurring at higher elevations, with temperatures at these higher elevations not accurately reflected in the temperature record, due to the differences in elevation. This might also cause issues with modelling of snow accumulation and melt by the degree day approach used within DWAT. Mr Fenwick still experienced (like during the first workshop) problems in running the DWAT on his laptop (though different from the one of the first workshop). His presentation highlighted the need to further expand the section describing snowmelt processes in the User's Manual. It also outlined the need to apply adjustments to the degree day parameters, influencing overall calibration. He also pointed out that running DWAT needs a considerable amount of expertise in modeling, and would therefore appreciate the development of appropriate training materials and a Community of Practice, especially for users that did not have the luxury of being involved in workshops of this nature. He also noted the problem he was having with the timing of rainfall and streamflow observation, especially for small basins, as few hours might negatively impact the model. He observed that there might be some "time stamp" issues with the meteorological or hydrometric gauges further compounding the modelling process. Mr Fenwick notes can be found in Annex 6.

3.6. Dr Yuri Simonov (Russian Federation, RA VI), through a video recorded prior to the workshop, showed the application of DWAT to the Oka river basin in Russia. His notes and those of his colleague Dr Andrei Khristoforov are provided in Annex 7. He underlined that all DEM aspects were dealt with outside of DWAT, using ArcGIS 10.4, with results being integrated later. Following his presentation on the application of DWAT and its comparison with observed data, he concluded that DWAT simulation results could be considered good even under the specific runoff conditions of the European part of Russia, especially if an output correction method is integrated. He felt that a correction or "updating" method was necessary to adjust the model outputs, thereby increasing model performance (Annex 8). It should be noted that he also presented such results using a monthly time step, with this time step being suited to water resources assessment needs and water balance modelling within Russia. His opinion was that DWAT allows good overall simulation of runoff using a monthly time step. He was contacted using webinar to clarify some formulas for bias and variance correction, and subsequently via e-mail.

4. Conclusions and Recommendations of DWAT Workshop

4.1. Participants reviewed the conclusions from the presentations, and discussed various aspects, agreeing on the following:

Bhutan case study

- DWAT simulation results were good under the specific runoff conditions tested in the Wangchu basin in Bhutan

- In this case study, DWAT is good at capturing trends and peaks of the flow
- ARIMA method used to correct simulation results showed improvement in performance

Argentina case study

- DWAT was capable of simulating the observed flows well (with high performance statistics) with a simple topology consisting of one catchment node and a routing link.
- lumped schemes performed better than the semi-distributed scheme tested (consisting of three sub catchments and one routing link).
- The importance of the modeler's expertise and judgement should never be neglected. Although automatic calibration performed better than manual calibration, resulting in higher performance statistics, manual calibration achieved a much better representation of base flows..
- Current DWAT version: this version is a promising tool for water resources assessment and management, and potentially for operational hydrological forecasting.
- DWAT is very flexible in admitting different temporal steps, even hourly. The available streamflow data for the Burrumayo basin was sampled at daily intevals, even when its concentration time is shorter than one day. Future testing of the model for the case of fast response catchments would be very informative.

Jamaica case study

- DWAT simulation results show some promising applications to the Wag Water River Watershed in Jamaica.
- Limited performance of the model might likely be attributed to a lack of initial availability of information on soils, matching the soils classification type with the one used in the model.
- Gaps in both available rainfall data and in the existing rainfall network negatively impacted upon simulation results.

New Zealand case study

- DWAT appears to be a good tool for water resources management.
- Application to this basin showed the importance of having reliable and representative rainfall data to drive the runoff process.
- Similar conclusions have to be made regarding temperature data needed to drive snow accumulation and melting processes.
- The documentation is still insufficient to allow easy application of DWAT for the novice.
- When the climatological series seem uncorrelated to the streamflow series, more effort is needed to obtain forcing data from other sources, e.g. satellite biased corrected estimates of precipitation, re-analysis, etc.

Russia case study

- DWAT simulation results could be considered good even under the specific runoff conditions of European part of Russia
- DWAT allows good simulation quality of runoff on aggregating daily data to a monthly time step, which is a suitable time span for water balance and resources assessment issues in Russia.

4.2. The experts agreed on the following recommendations:

- There is a need to further test DWAT for Water Resources Assessment and Management, on aspects such as new infrastructure impact assessment, different water uses, increasing demands and conflicting water uses, as well as the impacts of land use change or climate change and variability

- On occasion it might be beneficial to explore assessing daily modeling results versus those resulting from aggregating daily to a monthly time step.
- It may be beneficial to explore the ability of this modelling system to use monthly data when daily data are not available or are felt to be unreliable.
- Additional aspects that might help to improve DWAT usability and performance are:
    - Making a utility (tool) available that would allow users to easily access and input freely available global climatological data (e.g. precipitation, temperature, re-analysis data, etc.) land use and soil data
    - Addition of new observation stations in the upper catchment including higher elevations.
- Issues were noted when dealing with observed stream flow, climatological and meteorological data sets. Quality control and assurance should be undertaken before entering data into DWAT.
- In the User's Manual, there is the need for further explanation on how DWAT deals with gaps in data series, in particular how DWAT handles gaps in climate and streamflow observed data.
- DWAT should also have the ability to allow calibration of routing parameters and the threshold for computing degree days should be modifiable and be part of the automatic calibration/manual adjustment process.
- Consideration should be given to allowing greater flexibility adding the log Nash Sutcliffe efficiency (LNS) within the reported metrics during calibration. LNS flattens the runoff, and high flows and low flows are kept more or less at the same level. Model's good performance in low flow periods is very important for water resources assessment, possibly more important than a good simulation of high peaks, in many applications of WR management. Greater flexibility can also be achieved at calibration if it were up to the modeller the choice of the objective function to maximize or minimize, among the available metrics. Depending on the use of the model, a good volumetric fit may be preferred to peak or low flows accurate representation.
- The User's Manual should more adequately describe snowmelt accumulation and melting processes within the model, as this would increase understanding of the user on how to better adjust the parameters for snow applications.
- In addition to the User's Manual and available videos, additional support material (such as tutorials, example data sets, case studies) and a Community of Practice would be valuable to facilitate use of DWAT by users.
- Post processing of model output (i.e., "updating") should be undertaken to improve performance (e.g. ARIMA, linear regression approach - see for example, Goswami et al., Assessing the performance of eight real-time updating models and procedures for the Brosna River, Hydrology and Earth Systems Sciences, 9(4), 394-411, 2005 and WMO, Simulated Real-Time Intercomparison of Hydrological Models, Operational Hydrology Report No. 38, WMO-No. 779, 1992, pages 8-19. And also: Goswami, M., O'Connor, K.M., Bhattarai, K.P. and Shamseldin, A.Y. (2003). "Real-time river flow forecasting for the Brosna catchment in Ireland using eight updating models". The proceedings of the International Conferences on Advances in Flood Forecasting in Europe, Rotterdam, The Netherlands, held March 2003)

5. Closure of the workshop

6.1 The DWAT developers team expressed its appreciation for the effort undertaken by the regional experts in applying DWAT to their basins. The team greatly appreciated the feedback received from the regional experts that has resulted in improvements being made to DWAT itself, as well as allowing the evaluation of the Tool's performance in various basins around the world.

6.2 The representative of the Ministry of Environment, Republic of Korea, Dr Hwirin Kim, also expressed her appreciation for the hard work undertaken by the regional experts and the DWAT developers team, resulting in a successful conclusion to the 2nd Global DWAT Workshop. Participants and Dr Kim also wanted to express their appreciation to the Ministry of Environment, Republic of Korea, for all of its efforts in hosting the event. In particular, they wanted to thank, Mr Park, Director General of the Han River Flood Control Office, Ministry of Environment, Republic of Korea, and Hydrological Adviser to the Permanent Representative of the Republic of Korea with WMO, and his dedicated staff for having participated in the Workshop and for contributing to its success. Participants greatly appreciated the positive atmosphere that prevailed throughout the Workshop and wished to acknowledge the advances that have been made in the development of the Dynamic Water resources Assessment Tool since the 1st Global Workshop. Participants also indicated that they had enjoyed their stay in Seoul.

6.3 The current draft of the report will be circulated among regional experts who have participated in the modelling effort as well as the DWAT developers team for their review. It is requested that comments and revisions be submitted to WMO Secretariat in Word track changes mode by 28 June 2019. The WMO Secretariat will finalize the report by 31 July 2019 and circulate it to all Workshop participants.

6.5 The Workshop closed at 14:15 on Thursday 9 May 2019.

ANNEX 1

List of Participants – 2nd Global Workshop on Dynamic Water resources Assessment Tool (DWAT)

SEOUL, REPUBLIC OF KOREA

7 to 9 May 2019

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ANNEX 2

2nd Global Workshop on Dynamic Water resources Assessment Tool (DWAT)

TENTATIVE AGENDA

7 to 9 May 2019

Seoul, Republic of Korea

Tuesday 7 May – Day 1 Location: Han River Flood Control Office, 1st Floor, Conference room]

12:00 – 13:00	Lunch at hotel restaurant
13:00 – 13:30	Registration
13:30 – 13:50	Opening session and welcome address by • Director General of Han River Flood Control Office (HRFCO) • Chief, Hydrological Forecasting and Water Resources Division, WMO
13:50 – 14:00	Group photo
14:00 – 14:10	Introduction of the workshop agenda
14:10 – 15:10	DWAT Advances/modifications after 1st Global Workshop
15:10 – 15:30	Tea / coffee break
15:30 – 17:30	DWAT Advances/modifications after 1st Global Workshop (continued)
18:00 – 20:00	Welcome dinner hosted by Director of HRFCO (*Location: Sheraton Seoul – Tentative*)

Wednesday 8 May – Day 2 [Location: Koreana Hotel, 2nd Floor, Emerald Room]

09:00 – 09:30	Presentation on results of DWAT application by expert(s) from Regional Association I (RA I) – Africa
09:30 – 10:00	Presentation on results of DWAT application by expert(s) from Regional Association II (RA II) – Asia

10:00 – 10:30	Presentation on results of DWAT application by expert(s) from Regional Association III (RA III) – South America
10:30 – 11:00	Tea / coffee break
11:00 – 11:30	Presentation on results of DWAT application by expert(s) from Regional Association IV (RA IV) – North America, Central America and the Caribbean
11:30 – 12:00	Presentation on results of DWAT application by expert(s) from Regional Association V (RA V) – South-West Pacific
12:00 – 12:30	Presentation on results of DWAT application by expert(s) from Regional Association VI (RA VI) – Europe
12:30 – 13:30	Lunch break
13:30 – 14:30	Interactive session on assessing and adjusting DWAT applications [Moderator: Dr. Hwirin Kim]
14:30 – 15:00	Tea / coffee break
15:00 – 17:00	Interactive session on assessing and adjusting DWAT applications (continued)

Thursday 9 May – Day 3 [Location: Koreana Hotel, 2nd Floor, Emerald Room]

09:00 – 09:45	Discussion on requirements and future improvements for DWAT
09:45 – 10:45	Conclusions and recommendations of the 2nd DWAT Workshop
10:45 – 11:00	Tea / coffee break
11:00 – 11:45	Development of presentation story-lines for DWAT Symposium
11:45 – 12:30	Workshop report and closure
12:30 – 13:30	Lunch break
13:30 – 18:00	Field Trip – Visit to Hantan River Dam and DMZ *(Tentative)*
18:00 – 20:00	Banquet (*Location: Hyundai Motorstudio Goyang*)

ANNEX 3

DWAT Findings by Bikash Pradhan, Region II WMO

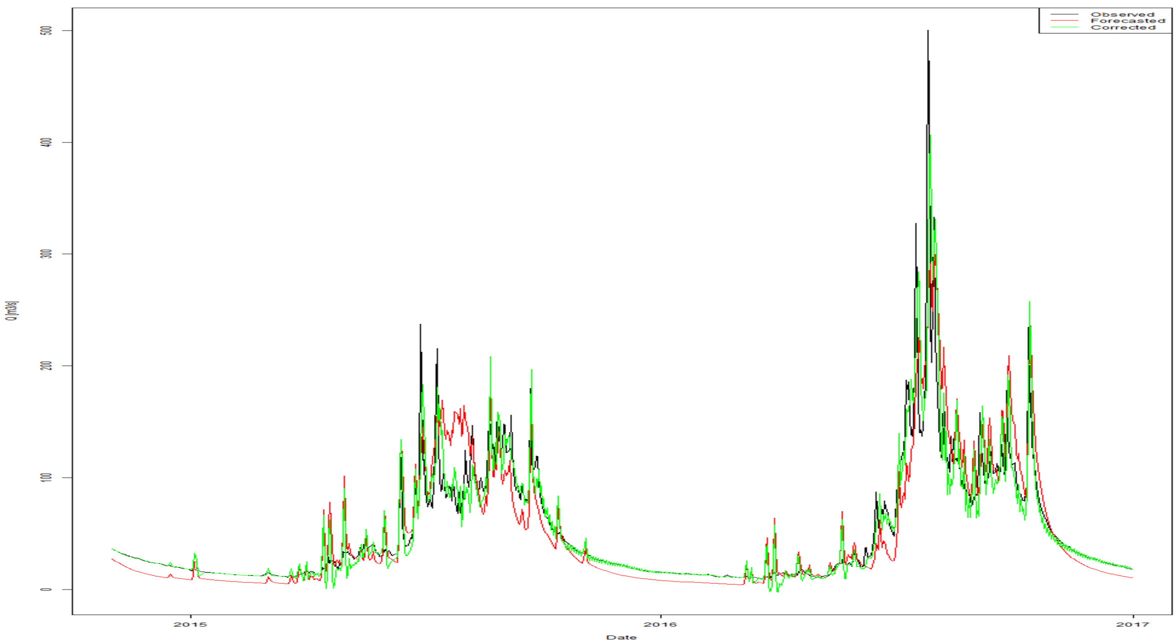
The application and verification of DWAT (Dynamic Water resources Assessment Tool) were carried out in Wangchu Basin using 10 meteorological station data where station weights were distributed by using Thiessen polygon method and single outlet was located at the lower end of the basin. The results from simulation are considered satisfactory and a simple correction was proposed and used. After correction, the results are better with applied correction in matching the observed discharge. Verification period of the model showed good simulation quality of runoff on a daily time step.

The hydrological and meteorological observation data series from 01.01.2013 -31/12/2014 was used for calibrating the model and 01.01.2015 – 31.12.2016 was used for validating the model. With the results from validation, some rather simple correction was applied to the results improving the simulated discharge values. The table and graph below shows that result of verification and correction of Daily discharges

Table 1: The results of verification and correction of Daily discharges.

Sl.No	River	Gauging Station	NSE	R2
1	Wangchu	Chukha	Without Correction: 0.74	Without Correction: 0.77
			With Correction: 0.84	With Correction: 0.85

Figure 1: Graph showing observed, simulated and corrected discharges of wangchu



Efficiency criterion used above demonstrated a satisfactory quality of simulation before the correction was applied and showed improvement in the simulated discharges after the correction was applied.

Strengths:

- DWAT simulation results are good under specific runoff condition of Bhutan
- In Bhutan's condition, DWAT is good at capturing Trends and peaks of the Flow
- Availability of video tutorials, though it might need fine tuning in future.
- Ability to simulate wide variety of environment variables in water resources management
- The results from the above daily water discharges coupled with output correction, DWAT model is a good tool for water resource assessment but can be used also as a short term forecasting tool.

Weaknesses:

- User interface has improved a lot compared to the previous version but still some more improvements needs to be done to make it more user friendly.

Area of improvement:

- Creating provision to extract global freely available data sets like meteorological parameters, Land use, Soil data, and other similar data set within DWAT would be beneficial to those having limited data set and are unable get the required data for running the simulation.

DWAT Findings by Marcelo Uriburu Quirno, Region III WMO

ON THE MODEL

Strengths

- DWAT is a link-node type model. It offers a broad variety of node options (catchment, wetland, paddy, reservoir, import (diversions), recycle, etc.) whose combination allows the user to simulate a wide range of environments in water resources management
- Broad variety of routing options
- Flexible when it comes to the potential evapotranspiration, computable by the model either with the Penman - Monteith equation or (now) with that of Hargreaves - Samani, or loadable as a time series
- Several formats supported for background layers, now including PNG.
- Both geographical and UTM coordinate systems are now supported
- Quick Start Tutorial videos are now available, though yet need fine tuning
- Very many more strengths!

Weaknesses

- The user interface has improved a lot but it is still not very friendly. It is difficult to manage the icons with the mouse
- The menus have to be expanded every time, which makes its use unnecessarily difficult and uncomfortable
- When a "project" is opened, it doesn't show the background, even if it had been previously saved with the background displayed
- For manual calibration, there are too many repetitive steps. It would be good if the software memorizes the last text / number insertions.

Future Improvements

- Solving the weaknesses mentioned above
- Inclusion of the possibility of automatic calibration of routing parameters
- When manual calibration is being done, it would be convenient to have opened the comparison chart of Qobs vs Qsim for visual inspection and, at the same time, be able to modify parameters.
- Widening the capability of the Reservoir node to allow the simulation of Detention ponds, a widely used Best Management Practice solution to compensate for the decrease in perviousness due to the increase of urbanization. The detention pond is usually dry with the ponded level growing during and immediately after a storm. This could be achieved by simply modifying the characteristic curve (Q[WSE]) to allow water levels below the pipe crown
- Error handling and error messaging still require improvement
- DWAT run results cannot be saved. It would be better that when a project is reopened, if its simulation results from a saved run would be accessible.
- DWAT should check for unrealistic, physically unfeasible or out-of-range values of parameters and/or variables, providing a warning if entered by the user

ON THE USER'S MANUAL

The user's manual has improved a lot. However, a deeper review of its current readability and completeness is yet to be done

DWAT Findings by Geoffrey Marshall, WMO Region IV

Strengths:

- Very robust software with built-in capacity to simulate vast majority of inputs and transfers from the water cycle for a range of time steps (hourly to monthly).
- Use of nodes and links for flow connections and system inputs (rainfall, weather, junctions, etc) allows for a clear schematic watershed model that can be as complex or as simple as needed.
- Calibration (either manually or automatically) can be quickly implemented.
- Results and fine-tuning from workshops 1 and 2 indicate a strong capacity to accurately simulate watershed activities, and the results also provide a basis for re-assessment of initial assumptions about watershed flow dymanics.

Areas for Improvement

- The software's learning curve is very high. While the manual provides good information to begin pre-processing of GIS data and establish the initial conditions, it also gives more detailed guidance for the software operation and data requirements aspects. The creation of an example-based tutorial, with sample data and step-by-step instructions/test cases for various problems and solutions would help many users to apply those steps to their own data and local situations. This tutorial and sample data could be downloaded alongside the installation software and operations manual.
- The software and manual assumes that all users are familiar with hydrology and have all the required data for the model operation, while the stated user base is "policy specialists and water resource managers". I would suggest that the target audience and data requirements be clearly specified. In its current state, the software is best used and appreciated by scientific researchers and professional hydrologists/engineers, etc.
- The data requirements for a robust simulation (minimum length of time, tolerance for data gaps, etc) should be stated by the DWAT developers in the manual so that potential users can know exactly whether their existing datasets can be used by DWAT to make a realistic simulation, and they can also know what to be measured/strengthened in their own data collection network to fully utilize DWAT. This is most applicable to developing countries that may not have the robust data collection network available in developed countries.
- There are still some operational "bugs" in the software that will require adjusting as encountered, and the software can be a bit exacting in its requirements. For example, it can be difficult to link two nodes if the link is not drawn "exactly" with the mouse.
- The version of DWAT tested at the 1st Global Workshop, held in Bhutan, was prone to crashing whenever it encountered a data snag or other user input error, without informing the user where the error may have been. The upgraded version of DWAT tested at the 2nd Global Workshop, while in Seoul, appears to be more resilient to

"crashing" than the Bhutan DWAT version, but could still benefit from a more directed error reporting capacity.

ANNEX 6

DWAT Findings by John Fenwick, Region V WMO

General:

Overall, DWAT appears to be a good tool for water resources management, and I can see that it could eventually be used by countries in the region, including the smaller Island countries.

I applied DWAT to a small mountain catchment in New Zealand with, initially, not very good results. In retrospect, the location was not a good choice as there exists a significant difference in rainfall between the catchment and the nearest climate station, from which the climate data was used.
However, with corrections applied to the rainfall data derived from a published study of rainfall gradients in the larger adjacent catchment, the water balance results were reasonable. Application to this basin showed the importance of having reliable and representative rainfall data to drive the runoff process, because the graphical outputs were able to demonstrate some time-stamp errors in that dataset.

As a non-modeller, I was challenged to understand some of the parameters available for tuning of the model, and this is an area in which the manual or other training material could be targeted.

Strengths:

There is a good range of options and parameters available for tuning the model, although some expertise is needed for this.

There is a good range of time steps that are usable for the data input.

The model handles gaps in data quite well (better than I expected, so that I was more selective with my dataset than I needed to be).

The results from the workshops showed the promise of the tool for water resources management, and I can see that it could eventually be used by countries in the region, including the smaller Island countries.

Areas for Improvement

The requirements for the input data for the GIS pre-processor need to be better described, particularly for the target audience of water resource managers who may not have a lot of hydrological modelling expertise.

The manual is quite comprehensive, but one or more case studies, perhaps shown by video clip, would greatly enhance the learning curve – which is relatively steep, especially for non-specialist water resources practitioners. Further, a community of practice should be established.

The requirements for datasets need to be specified better in the manual. I made some wrong assumptions as to the need for zero gaps in the time-series, which unnecessarily limited my choices.

At both workshops I had trouble running the software and could only do so with the help of the developer providing me with some sort of “patched” version, and no particular reason for the problems were evident. One possibility was that some file path names were too long but this was not established.

When DWAT crashes, it usually provides no error messages, so it can be tedious and frustrating to get it to run sometimes. Thus some tests, such as for checking imported file formats, should be implemented and relevant error messages need to be provided.

The tools for handling snowmelt, and for the temperature data needed to drive snow accumulation and melting processes, could do with some refinement, at least for conditions such as the New Zealand mountains.

DWAT Findings by Yuri Simonov and Andrei Khristoforov, WMO Region VI

The application and verification of DWAT for the Oka River basin in Russia (part of the Volga river basin) were accomplished. The simulation results are considered to be satisfactory. A simple but rather effective output correction method was proposed and used. After the application of such a correction approach, the results of the DWAT simulation are considered to be improved. As an additional modelling effort, the monthly water discharges were simulated. These can be of particular importance for water balance and water resources estimation. Verification results showed that DWAT provides a runoff simulation using a monthly time step that is of good quality.

The training sample for model calibration comprises the hydrological and meteorological observation data series for the periods of 01.08.2010 – 31.12.2012 and 01.01.2014 – 31.07.2015. These are equivalent to an observation data series having 4 years. The validation sample for model verification comprises hydrological and meteorological observation data series during 2013. At the same time, these results illustrate the need to employ a method to automatically correct or adjust the simulated discharges. To do so, a rather simple output correction method was proposed. The table 1 lists the results of the statistics of the modelled derived discharge and statistics of the corrected or adjusted daily discharges.

Table 1. The results of calibration and correction of daily discharges

daily discharges			without correction			with correction		
River	Gauge	R	S	S/σ	NSE	S	S/σ	NSE
Upa	Orlovo	0,77	69,2	0,73	0,46	51,2	0,54	0,71
Zhizdra	Kozelsk	0,71	74,2	0,76	0,42	58,5	0,60	0,64
Ugra	Tovark.	0,75	232	0,69	0,52	188	0,56	0,68
Oka	Kaluga	0,85	316	0,57	0,67	205	0,37	0,86

Comments: R – correlation coefficient between simulated and observed discharges, S – standard error of simulation, σ – standard deviation of observed discharges, S/σ – model efficiency criterion, used in Russia; NSE – Nash-Sutcliffe efficiency criterion.

Efficiency criteria demonstrate the satisfactory quality of DWAT simulated results before the proposed correction, and the results indicate a significant increase in the accuracy of the estimations after its application. The most important results are for the Oka River near Kaluga. It is the most downstream river section, so DWAT's daily discharges simulation integrates the results of for the entire study territory. For this most important river section, the results obtained are also the best.

The proposed correction method leads to a reduction in the standard error of the simulation of more than one and half times.

For the purposes of water balance and water resources estimation, the monthly water discharges can be more suitable than daily discharges. That is why the DWAT simulation of runoff using a monthly time step was analyzed. The statistical performance of monthly discharge estimation were based using observed versus simulated daily discharges. The corrected daily simulated water discharges should be used to obtain the monthly water discharges. There is no need to correct the simulated monthly discharges themselves. The table 2 contains the results of verification of corrected monthly discharge values so obtained. The correlation coefficient and the Nash-Sutcliff efficiency index increase for the corrected values, and the relation between the standard error and the standard deviation is smaller than they were in the same table for daily discharges.

Table 2. The results of calibration and correction of monthly discharges.

monthly discharges			without correction			with correction		
River	Gauge	R	S	S/σ	NSE	S	S/σ	NSE
Upa	Orlovo	0,94	21,4	0,61	0,63	12,2	0,35	0,88
Zhizdra	Kozelsk	0,91	22,2	0,62	0,62	14,7	0,41	0,83
Ugra	Tovark.	0,87	65,9	0,66	0,57	48,9	0,49	0,76
Oka	Kaluga	0,98	154	0,51	0,74	96,7	0,32	0,90

For the final river section Oka near Kaluga, its results are again the best. Consequently, the quality of DWAT's simulation for a monthly time step is better than for daily. The proposed output correction method has proven to be effective for monthly discharges, as it was for daily discharges. For the final river section Oka near Kaluga, it results in a reduction to the standard error of the simulated data by more than one and half times again.

In conclusions in can be noticed that:

- DWAT simulation results are considered to be good even for the specific runoff conditions of the European part of Russia;
- Proposed output correction method results in a significant improvement in the quality of the simulation;
- DWAT provides a good simulation quality of runoff on a monthly time step, which is suitable for water balance and resources assessment issues;
- The overall good quality of DWAT simulations of daily discharges when an output correction is applied supports the recommendation that DWAT with a correction applied

is suitable for water resources assessment but for short-time hydrological forecasting as well.

ANNEX 8

Output Correction/Update Method

by Andrei Khristoforov and Yuri Simonov

You use the training sample for model calibration that would include hydrological and meteorological observation data series during some time period.

This training sample contains *N* observed streamflow discharges, $Q_1, \ldots, Q_N$.

You would use this sample to calculate their standard statistical estimates of the Mean, $\overline{Q}$, and Standard deviation, σ :

$$\overline{Q} = \frac{1}{N}\sum_{i=1}^{N} Q_i \ , \tag{1}$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Q_i - \overline{Q})^2} \ . \tag{2}$$

Following the calibration of DWAT, you would use N simulated streamflow discharges, Q_{S1} ,…, Q_{SN} , to calculate their estimates of the Mean, $\overline{Q}_S$, and Standard deviation, σ_S :

$$\overline{Q}_S = \frac{1}{N}\sum_{i=1}^{N} Q_{si} \ , \tag{3}$$

$$\sigma_S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Q_{si} - \overline{Q}_S)^2} \ . \tag{4}$$

You would then compute the standard estimate of Pearson's correlation coefficient between the observed and simulated discharges:

$$R = \frac{\frac{1}{N-1}\sum_{i=1}^{N}(Q_i - \overline{Q})(Q_{Si} - \overline{Q}_S)}{\sigma\sigma_S} \ . \tag{5}$$

The corrected or updated simulated discharges, Q_{SC}, would then be calculated with the help of the formula:

$$Q_{SC} = \overline{Q} + R\frac{\sigma}{\sigma_S}(Q_S - \overline{Q}_S) \ . \tag{6}$$

This is in essence an application of linear regression that is well known in Mathematical Statistics and Statistical Hydrology.

The Mean of the corrected simulated discharge is equal to the Mean of the observed discharge: $\overline{Q}_{SC}=\overline{Q}$. So the suggested output correction or updating method removes the systematic error that arises in the simulation.

The standard deviation of the corrected or updated simulated discharges is equal to $\sigma_{SC}=R\sigma$. It is less than the standard deviation of observed discharges, σ . In the case of rather high correlation existing between observed and simulated daily streamflow discharges, where the correlation coefficient R would be close to 1, the difference between σ_{SC} and σ would be small. So in this particular application of the DWAT to Russian rivers, the magnitude of the temporal variability of observed and corrected or updated simulated discharges are very close.

All parameters of correction ($\overline{Q}$, σ , $\overline{Q}_S$, σ_S , R) in formula (6) must be estimated using the training sample. As the size of the training sample increases, the accuracy of the estimates of the correction or updating parameters in equation (6) will also increase.

The corrected or updated simulated streamflow discharges should be used to estimate monthly streamflow discharges. There is no need to apply any additional correction to the simulated monthly discharges that were calculated using corrected or updated daily values.

When verifying the performance of DWAT, use should be made of the corrected or updated simulated daily streamflow discharges. These should be estimated using formula (6), where its parameters are estimated from the training sample.

The results from the application of the suggested method of output correction or updating are dependent on the estimate of the parameters of DWAT and on the statistical estimations of the parameters of equation (6) that are based on the training sample of observed and uncorrected estimates of streamflow discharge.

If you wanted to perform a climate change simulation study reflecting an altered meteorological regime, while using the same parameters of DWAT as estimated from data of the current regime, you can use the suggested Output Correction/Update Method without any problems. The resulting DWAT simulated daily streamflow discharges should be then be corrected/updated using equation (6) and the previously estimated parameters of the correction. It should be noted that the resulting corrected or updated discharge series will have a reduced standard deviation as compared with the original discharge series of $R\sigma$. The percentage reduction in variance in the adjusted series would be $100(1-R)^2$. A different correction method would be needed to preserve the statistics of the original series.

If you wanted to perform a climate change simulation study an altered meteorological regime and with the new parameters of DWAT consistent with this new regime, performance of the application of the suggested Output Correction/Update Method based on statistics of the training period, which are reflective of the unaltered regime, cannot be guaranteed.