1st Global Workshop on
Dynamic Water resources Assessment Tool (DWAT)

FINAL REPORT

THIMPHU, BHUTAN

28 to 30 November 2018

1. Opening Session

1.1 At the kind invitation of the Government of Bhutan, and with the financial contribution of the Republic of Korea, the 1st Global Workshop on the Dynamic Water resources Assessment Tool (DWAT) was held in Thimphu, Bhutan from 26 to 28 November 2018.

1.2 The meeting was opened at 13:30 on Wednesday 28 November 2018 at the Jambayang Resort. Purpose of the workshop is to make the DWAT known to experts from all WMO Regions.

1.3 Mr Karma Dupchu, Director of the National Centre for Hydrology and Meteorology (NCHM) of the Royal Government of Bhutan and Permanent Representative of Bhutan with WMO, welcomed participants to the Kingdom of Bhutan. He expressed his appreciation towards WMO and Korea for the support provided in hosting the Workshop. Bhutan has the highest pro-capita availability of water, but management of water resources is sometimes complicated by the topography. Extremes are occurring seasonally, with monsoon season bringing floods and low flows during the dry season. Urbanization and increase of population, combined with climate change, are posing a threat to proper water resources management. Water use is mainly directed to hydropower plants, followed by agricultural and domestic consumption. With an increase of electricity demand during winter, water resources become scarce. This combines with the seasonal low flows and therefore affect water quality for domestic uses. DWAT is therefore of utmost importance for Bhutan, being a tool useful for water assessment. As such, not only staff from NCHM but also representatives from the academia of Bhutan are going to attend the workshop. Finally, he wished participants a fruitful workshop.

1.4 Dr Hyoseob Cho, Director of the Water Resources Information Center, Han River Flood Control Office, Ministry of Environment of the Republic of Korea, deeply appreciated the warm hospitality of the NCHM staffs and welcomed all participants including the WMO Secretariat and international experts on behalf of the Republic of Korea. He underlined the variability of freshwater resources due to climate change, hence the challenge posed by 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 to develop and distribute at the international level the DWAT.

1.5 Dr Paul Pilon, Chief of Hydrological Forecasting and Water Resources Division, WMO Secretariat, thanked the previous speakers, as well as the participants from Bhutan and abroad, and welcomed everybody on behalf of Prof. Petteri Taalas, Secretary General of WMO, to the 1st Global Workshop on the DWAT. He expressed particular appreciation to the role of the Republic of Korea in developing the DWAT and in organizing and financing the Workshop. Dr Pilon underlined the importance on 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 available for free to the international community. This 1st Workshop provides an opportunity to have international experts who have reviewed the DWAT and the same software developers sit around the same table and exchange on the software usability; at the same time, this Workshop will provide an opportunity to other participants to have a direct hands-on experience on the functionalities of the DWAT.

2. Introduction of Participants and workshop programme

2.1. Participants introduced themselves. 27 participants from eight countries and two WMO staff attended the Workshop. Around half of the participants were from Bhutan. Four of the international participants were invited as experts from different WMO Regional Associations, namely region II (Asia), III (South America), IV (North America and Caribbean), V (Pacific)

and VI (Europe). Due to a last minute health impediment, the expert from Region I (Africa) could not attend. List of Participants is provided in Annex 1.

2.2. After the Workshop programme presentation by Dr Hwirin Kim, Dr Hyeonjun Kim provided a presentation on the purpose, capabilities and performance of the DWAT. The presentation is available at the website https://public.wmo.int/en/water/dynamic-water-resources-assessment-tool. It focused mainly on the theoretical basis of the DWAT.

2.3. A hands-on demonstration of the DWAT functionalities was then performed by Dr Cheolhee Jang. Time was then given to the experts from the regions to further run the model and discuss with the Dr Jang and Dr Hyeonjun Kim shortcomings and troubleshooting.

3. Results of DWAT application

3.1. Previous to the Workshop, the six regional experts were provided the DWAT software and user manual package, with the objective of testing the DWAT on local basins and comparing the output with observed data. The experts presented their experiences in running the DWAT as per the following paragraphs.

3.2. Mr Bikash Pradhan and Mr Tandin Wangchuk (Bhutan, RA II) expressed their concern regarding the user manual, as it does not contain step-by-step procedures to run the model. They thought that a series of screenshots to guide the user would be helpful. They also underlined the presence of what they thought were some bugs in the software, e.g. while inputting land-use data the software automatically re-starts. It was later established that the difficulty of what they thought was a bug was in fact due to not checking an appropriate box. In terms of hydrometeorological data required by the model for their test basin, Mr Pradhan and Mr Wangchuk didn't express particular concern, as most of the required data were available from NCHM. However, they did express concern should they attempt the model to more data sparse regions of Bhutan. They noted that the DWAT, through the combination of different models, could also be used for flood forecasting. However, this functionality is not mentioned in the User Manual. Even though Mr Pradhan and Mr Wangchuk started working on applying DWAT to one basin in Bhutan a couple of weeks before the Workshop, they only were able to input DEM, land-use, and soil data into DWAT during the Workshop. They ascribe this lack of progress in the modelling effort to the initially mentioned lack of step-by-step guidance in the user manual.

3.3. Mr Marcelo Uriburu Quirno (Argentina, RA III) provided a detailed set of comments and feedback, which can be found in Annex 3.

3.4. Mr Geoffrey Marshall (Jamaica, RA IV) appreciated the dynamic aspects of the DWAT, specifically how it brings together evapotranspiration and precipitation in real-time. He felt that the user manual is a little bit too detailed on theoretical aspects, but somehow was lacking the necessary step-by-step instructions to allow an unfamiliar user to implement the software. Many important steps needed to run the DWAT were not captured in the user manual. He appreciated the clarity of the user manual for the pre-processing phase, but felt it would benefit from additional detail on the software running phase. The meteorological input data needed by the model are significant, and many of the required data (elements such as solar radiation, wind speed) were not available at the national level. This entailed a significant amount of extrapolation, making the output potentially not reflective of reality. In his experience, a considerable amount of manual adjustment of the parameters was needed, but this was not specified in the user manual and was therefore made evident only through consultation with the system developers. In summary, Mr Marshall expressed his appreciation for the potential usefulness and utility of this software for a National Hydrological Service, but underlined that the documentation is not intuitive for a first-time user, but likely is so for those that developed it. He noted that he was only able to

successfully run the model at the Workshop thanks to the guidance provided by the developers.

3.5. Mr John Fenwick (New Zealand, RA V) provided a detailed set of comments and feedback, which can be found in Annex 4.

3.6. Dr Yuri Simonov (Russian Federation, RA VI) provided a detailed set of comments and feedback, which can be found in Annex 5.

4. Discussion on DWAT applications and its possible future improvements

4.1. Assessment of the DWAT results was performed by the six regional experts from five regions. The objective of this session was to have them share their opinions, critically and objectively, about DWAT, their experiences gained through its application, and its potential usefulness. Dr Hyeonjun Kim presented a summary of the results obtained by the experts (presentation provided on the WMO website) on each of their modelling applications, and a first assessment of the modelling results was provided. The presentation was carried out in an interactive way, with comments and interventions from the floor, which are reported in the following paragraphs.

4.2. It was noted that for a variety of reasons the regional experts were unable to obtain final results before the Workshop. The various reasons were resolved at the Workshop, which underlines the importance of having this event. It was recognized that the results attained through the efforts of modelers at the Workshop should still be considered preliminary. It would be beneficial if following the Workshop the developers were to continue working with the regional experts to further refine the application of DWAT to their local basins.

4.3. The first main discussion item was about the delineation of catchments. All of the experts encountered problems, with the DWAT crashing when it ingested the high resolution DEM data for some basins (see Annex 5 for more details on coordinate system issues). It was explained by the developers that the DWAT GIS Preprocessor was built specifically to assist model application and is not a broad GIS. However, it was suggested that DWAT requirements for shape files could be met using other compatible GIS software such as QGIS, which is freely available. A manual option to prepare and correct the delineations should also be made available. Documentation should mention and include information and guidance on how to do delineation via QGIS, or other freely available systems, and through the software embedded in DWAT. Possibly an online tutorial should be developed to facilitate this process for the uninitiated. The maximum size of the catchment that can be delineated should be mentioned in the User Manual, so that users could divide the basins into sub-basins. It was noted that the grid size combined with basin size needs to be assessed to ensure that it can be supported by the DWAT GIS Preprocessor. Also, the number of sub-basins can also be limited by processing speed of the computer.

4.4. The issue of DWAT crashing might also be attributed to the computational capability of the computer on which DWAT is being run. The hardware and software (OS) requirements are specified in the User Manual. It was noted that one expert experienced difficulties for unexplained reasons that will be further investigated by the developers. It was also noted that crashing did occur as a result of being run with the model being not properly set up (rather than being given an error message when some parameters had not been set up properly, pointing to where the specific issue lies).

4.5. During discussion it came out that there was no expectation from the developers to have the regional experts succeed in the implementation of DWAT prior to the Workshop. However, it was felt to be beneficial to move towards a Community of Practice (CoP) approach, i.e. where NHS experts could successfully implement and run DWAT without the need to consult with the developers through, in particular, a face-to-face training session.

One approach considered was to develop a CoP specifically for DWAT to address any specific questions or issues and share results. It is anticipated that this will require a considerable effort and will not be realized in the short term, but as a long-term goal.

4.6. Application of the DWAT to the basins considered by the regional experts showed that additional efforts were needed to improve results. It also became apparent that a preliminary water balance analysis was needed as a first step, which would help potential application of the model to the data. It would be helpful if how to do this could be mentioned in the future version of the User Manual. The goal of the current version of the User Manual is to explain how to run the model, not how to fine tune it. Another point raised was regarding calibration for the case of Argentinian basin. Results were considerably worse after calibration than before. This was felt to be a result that automatic calibration did not take into account the routing. Routing parameters should therefore be included in the optimization.

4.7. Considering that the aim of WMO is to assist its Members (particularly Least Developed Countries and Developing ones), consideration was given to the operability of the DWAT as a tool freely available to WMO Members. To use DWAT however needs rainfall data, temperature data, etc. Data availability might be an issue in many countries as many elements are needed to run the model. It is known though that most WMO Members would not have a sufficient data collection network. How to proceed in data-poor situations is something to be further considered. Investigating the literature might be an option, even though doesn't seem as an easy solution. Another option would be to include less data intensive potential evapotranspiration equations/methods. Estimates of precipitation can also be obtained using approaches such as the FFGS Hydroestimator (real-time bias correction). Should the basin within an FFGS application area, exporting of its data to DWAT could be considered. It was noted that sharing of approaches on how this is achieved within the FFGS could be shared with DWAT developers and that this would be helpful. WMO Secretariat could provide such information.

4.8. Problems were encountered with attenuation of runoff from rainfall events in the case of New Zealand. Base flow was largely underestimated, with overestimation of peak flows in the simulation. Observed discharge data were checked and considered accurate.

4.9. In the case of Jamaica, the model attributed no discharge from surface runoff, and most of the runoff came from groundwater. This does not reflect the actual conditions of the basin. This implies that there needs to be some additional adjustment to the basin parameters.

4.10. In the case of Russian Federation, the snowmelt runoff was not modelled correctly, with modelled results differing considerably from the observed data; even using the calibrated parameters for the snowmelt module of DWAT did not provide good results. Further investigation is needed by the developers. The developers noted that they would need assistance from a snowmelt modelling expert.

4.11. It was mentioned that applications of DWAT could also be shared with the WMO Global Hydrological Status and Outlook System (HydroSOS).

4.12. It was also mentioned that the utility of DWAT could be further expanded to include the area of hydrological forecasting. This expanded functionality could be considered but it is not part of the current development plan.

5. Conclusions and Recommendations of DWAT Workshop

5.1. There was agreement among participants that the development and implementation of the DWAT will significantly improve the capabilities of NMHSs to better understand the timing and distribution of water resources at the basin scale as well as nationally. The regional experts applying the model found DWAT to be generally easy to use and having a large potential for applications in water resources assessment. Participants appreciated the usefulness of the Workshop to learn first-hand how to implement the model, and they also recognized that their application to local basins did not explore the full potential of the DWAT for assessing water uses, such as water extractions for irrigation or inter-basin transfers, within the basin versus availability. This extended analytical capability would need to be further explored in order to assess DWAT functionalities as well as to take advantage of them. It was felt that this could potentially be more formally assessed through a future Global DWAT Workshop where application basins are carefully selected that reflect significantly modified upstream flows due to water use.

5.2. Regional experts found that applying DWAT to one of their basins led to valuable insights on how to potentially improve the modelling system and its documentation. As well, regional experts provided their views on the usefulness of the User Manual and how the system's implementation could be improved through the provision of expert guidance. These applications and observations led to specific conclusions and recommendations. A number of minor ones are provided in the annexes 3, 4 and 5 as well as in sections 3.2 and 3.4, while major ones are appearing in the following paragraphs.

5.3. The DWAT GIS Preprocessor is currently limited based on DEM resolution versus basin size for its delineation. It was recommended that advice be given to users on these limitations and material be included for use of freely available GIS software, which might not have such limitations. It was felt that DWAT GIS Preprocessor was not meant to be a GIS package, but rather advantage should be taken of existing systems for outlining shape files that are compatible for use within DWAT.

5.4. The minimum hardware and software (OS) requirements have been provided by the developers to ensure correct functioning of the DWAT system. Additional efforts are needed to develop additional requirements as it was made evident during the Workshop that the existing requirements were not sufficient to allow the system to function on one pc.

5.5. Experts felt that the User Manual needs improved step-by-step instructions, as some important steps or features were not mentioned. It was also felt that the detail on theoretical material contained in the User Manual could be assigned to an annex. It is important that the theoretical underpinning of the modelling approach be contained in the User Manual. It was also emphasized that the User Manual and software should come with a quick start tutorial, with an example being cited of the EPA SWMM User Manual (https://www.epa.gov/water-research/storm-water-management-model-swmm).

5.6. It was recommended the User Manual provide some simple examples that would be helpful in allowing users to gain some valuable insights on how to set up data input, how to schematize the basin (such as number of sub-basins to consider and their preferred sizes). This could also include an example of how to delineate a basin, using either the DWAT GIS Preprocessor or a freely available GIS.

5.7. In concert with the above, it was felt that guidance is needed on how to approach modelling in general using DWAT, such as adjusting and fine tuning the model parameters and schematizing basins. As an example, it was pointed out that the first step should be in performing a preliminary annual water balance prior to applying the hydrological modelling component within DWAT. This was raised as for some of the applications it was apparent that there were issues with attaining a water balance. The results obtained from the five

modeled basins indicated that further work was needed to improve model performance, but that additional guidance could be given on how to do so.

5.8. It was observed for a particular sub-basin (see Argentinian case) that a better replication of observed discharge required the inclusion of additional basin storage effects in order to adjust the noted time shift between simulated and observed hydrographs. This was efficiently done by adding a routing component (Muskingum model) to the link between the catchment node and the outlet node. However, the routing parameters had to be manually calibrated since the current DWAT version does not include the possibility of automatically calibrating its routing parameters. It is recommended that attention be given to rectifying this situation in future updated model versions.

5.9. As well, it was pointed out that additional attention was needed on improving snowmelt modelling particularly for basins experiencing significant snow accumulation.

5.10. It was noted that to use the current version of DWAT requires extensive meteorological data. It was felt that such data requirements are too demanding for many countries, specifically when dealing with data for small basins. Regional experts indicated that it would be desirable to allow modelling options within the system that do not have such extensive data requirements. Discussion also explored other options other than ground-based observations to drive the hydrological modelling within DWAT. Specifically, it was felt that the developers could explore acquiring either reanalysis data or NWP model data for use in DWAT. This may require interfaces to such data sources and guidance on how to do so. Similarly, there is discussion on making best use of advances in satellite estimate of precipitation such as the Global Hydroestimator available from the FFGS or directly through NESDIS, noting that it needs to be real-time adjusted for bias using ground-station data. WMO Secretariat could assist the developers in making the appropriate linkages in this area.

5.11. It was underlined that concerted efforts would be needed to make the DWAT more easily implementable by national experts not familiar with its development. These efforts would include revisions to the User Manual as recommended above, the development of training material such as online tutorials and the development of a Community of Practice (CoP) for DWAT. This CoP would act as a helpline as well as allowing a sharing of experiences and the results obtained among NMHSs and the model developers.

5.12. It is recommended that the developers work closely with the regional experts to fine tune the application of DWAT to their respective basins. These results should be made available at a later date and be posted with the report of the Workshop as they should be illustrative of the additional benefits made possible through the expert knowledge of developers working closely with the regional experts over an additional period of time.

5.13. The regional experts wished to express their appreciation to the DWAT developers for all of the efforts undertaken in the development of DWAT and in assisting them in its application. They recognized that the efforts undertaken by them were preliminary and that improved results would be achieved through additional efforts. The regional experts wish to stress that they see that the DWAT will be beneficial to NMHSs and hope that the developers will positively consider the conclusions and recommendations leading to what they feel are improvements to the system. It is suggested that a future Global DWAT Workshop be considered following integration of the improvements to the system.

5.14. The regional experts also wanted to express appreciation to the Ministry of Environment, Republic of Korea, for the kind support provided to the development of DWAT.

5.15. Recalling that an external peer review is in progress under the auspices of the Commission for Hydrology, it was recommended to keep in consideration the future outcomes of this review process when establishing next steps for the further development and refinement of

DWAT. It should be noted that two of the three independent reviewers have participated in this Workshop.

5.16. It is recommended that the 1st Global DWAT Workshop report be published on the DWAT website, to be developed by the WMO Secretariat. It is further recommended that publication of the Manual and the software including launching of the CoP on the DWAT website be undertaken once improvements to the system will have been completed.

6. Closure of the workshop

6.1 The DWAT developers team expressed its appreciation of the effort undertaken by the regional experts in applying DWAT to their basins. The team greatly appreciates the feedback received from the regional experts and looks very much forward to continued collaboration to improve the results from the local basins and DWAT itself.

6.2 The representative of the Ministry of Environment, Republic of Korea, Dr Hwirin Kim, expressed also her appreciation for the hard work undertaken by the regional experts and DWAT developers team, resulting in a successful conclusion to the 1st Global DWAT Workshop. Participants and Dr Kim also wanted to express their appreciation to the National Center for Hydrology and Meteorology (NCHM), Royal Government of Bhutan, for all of its efforts in hosting the event. In particular, they wanted to thank Mr Karma Dupchu, Director of NCHM and Permanent Representative of Bhutan with WMO, and his dedicated staff for actively participating in the Workshop and for contributing to its success. Participants greatly appreciated due to the positive atmosphere that prevailed throughout the Workshop, and their stay in Bhutan.

6.3 Mr Sangay Tenzin on behalf of NCHM and the Royal Government of Bhutan wished to express appreciation to the Ministry of Environment and the Korea Institute of Civil Engineering and Building Technology (KICT), Republic of Korea, and WMO for their technical and financial support to hosting a successful Workshop.

6.4 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. No revisions are expected for chapters 3, 4 and 5. It is requested that comments and revisions on chapters 1 and 2, as well as the annexes, be submitted to WMO Secretariat in Word track changes mode by 15 December 2018. The WMO Secretariat will finalize the report by 21 December 2018 and circulate it to all Workshop participants.

6.5 The Workshop closed at 21:40 on Friday 30 November 2018.

ANNEX 1

1st Global Workshop on Dynamic Water resources Assessment Tool (DWAT)

THIMPHU, BHUTAN

28 to 30 November 2018

Provisional Programme

(Status 28 November 2018)

Wednesday 28 October

Lunch Time (12:00 – 13:00) at hotel restaurant

Registration (13:00 – 13:30)

Day 1 Afternoon: Introduction and Overview of Water Resources Assessment Methodsand Requirements (Moderator: Dr Hwirin Kim) (13:30 – 17:00)

- Opening of the session and Welcome speech by WMO Permanent Representative of Buthan, Royal Government of Bhutan (RGOB), NCHM Director Mr Karma Dupchu
- Opening Remarks by representative of the Han River Flood Control Office (HRFCO), Ministry of Environment, Republic of Korea, Director of Water Resources Information Center Dr. Hyo Seob Cho
- Opening Remarks of representative of WMO, Chief of Hydrological Forecasting and Water Resources Division Dr Paul Pilon
- Group Photo
- Introduction of participants and the workshop programme (Hwirin Kim)(13:50 – 14:10)
- Overview of the purpose, capabilities and performance of the Dynamic Water resources Assessment Tool (DWAT) (Dr Hyeonjun Kim) (14:10 – 15:00)
- Coffee break (15:00 – 15:20)
- Demonstration of the DWAT (Dr Cheolhee Jang) (15:20 – 17:00)

Welcoming Dinner (18:00 – 20:00) meet at Lobby hosted by Director of the Han River Flood Control Office (HRFCO), Korea Ministry of Environment (ME)

Thursday 29 October

Day 2 Morning: Results of DWAT application by Participants (Moderator: Dr Hwirin Kim) (09:00 – 12:00)

- Presentation on the results of application: RA I (Uganda) Mr Tom Kanyike– absent
- Presentation on the results of application: RA II (Bhutan) Mr Bikash Pradhan, Mr Tandin Wangchuk
- Presentation on the results of application: RA III (Argentina) Mr Marcelo Uriburu Quimo
- Coffee break
- Presentation on the results of application: RA IV (Jamaica) Mr Geoffrey Marshall
  Presentation on the results of application: RA V (New Zealand) Mr John Fenwick

- Presentation on the results of application: RA VI (Russia) Dr Yuri Simonov

Lunch Time (12:00 – 13:00)

Day 2 Afternoon: Assessing and Adjusting DWAT Applications (Moderator: Dr Hwirin Kim) (13:00 – 17:00)

- An initial assessment of application results by Dr Hyeonjun Kim
- Interactive Session: Fine-tuning/Adjusting DWAT Applications (WMO Region experts and DWAT Development Team)

Friday 30 October

Day 3 Morning: Continuation of Interactive Session (Moderator: Dr Sung Kim) (09:00 – 12:00)

- Interactive Session: Fine-tuning/Adjusting DWAT Applications (WMO Region experts and DWAT Development Team) (09:00 – 10:30)
- Coffee break (10:30 – 10:50)
- Discussion on future improvements of DWAT (10:50 – 12:00)

Lunch Time (12:00 – 13:00)

Day 3 Afternoon: Workshop on Dynamic Water resources Assessment Tool (DWAT) (Moderator: Dr Paul Pilon) (13:00 – 17:00)

- Conclusions and Recommendations of DWAT Workshop (13:30 – 15:00)
- Coffee break (15:00 – 15:20)
- Workshop report and closure (15:20 – 16:30)

※Schedule for the DWAT Workshop

- **Provide DWAT program and manual (2 October)**

  - Any commercial use or unauthorized reproduction of the program and the user manual are strictly prohibited. (The copyright of the DWAT is reserved by KICT & HRFCO.)

- **Applying DWAT to a test basin by WMO experts (3 October to 11 November)**

  - Participants need to send the application results to the DWAT Development Team (Dr Cheolhee Jang, chjang@kict.re.kr) by 11 November.

  - When you send the results of the application, send the following contents.

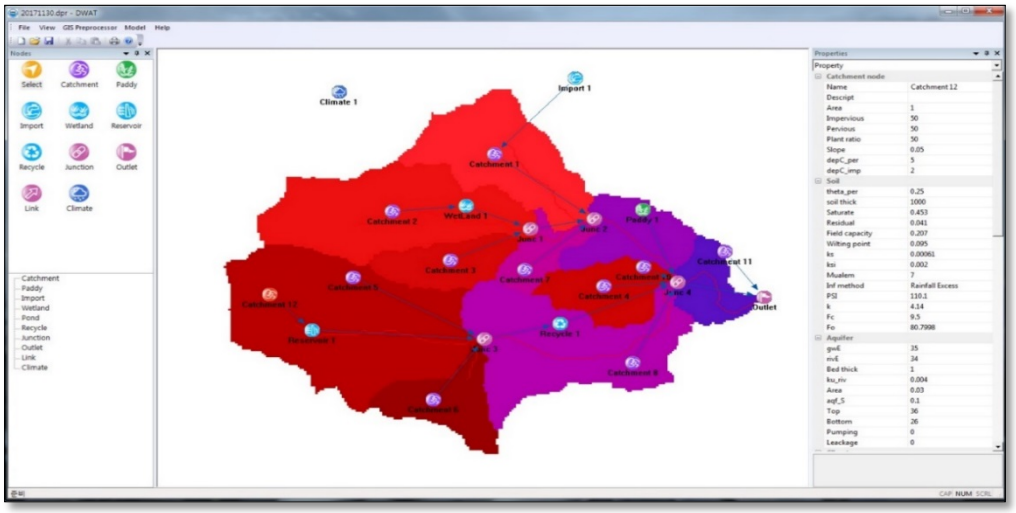
    ①Description of the test catchment such as area, stream network, soil type, land use and etc.

    ② System configuration including Input data such as rainfall and climate

    ③ Calibration results including observed streamflow

    ④Applying results such as water balance, scatter chart and etc. (Using graph and table)

  - Your application results will be shared during the workshop through presentations.



< Example of system configuration>

  - If you have any problem in applying the DWAT, please contact the DWAT Development Team for assistance(Dr Cheolhee Jang, chjang@kict.re.kr)by 11 November.

- **Review of the application results by the DWAT developers (12 to 23 November)**

  - The DWAT Development Team will review the application results received and will present an overview of the results during the workshop.

- **Workshop (28 to 30 November)**

  - Presentation on the application results by each WMO Regional expert.

  - Presentation on the overall results by the DWAT Development Team.

  - Discussion on potential future improvements to DWAT

ANNEX 2

List of Participants - 1st Global Workshop on Dynamic Water resources Assessment Tool (DWAT)

THIMPHU, BHUTAN

28 to 30 November 2018

Argentina	
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ANNEX 3

Dynamic Water Resources Assessment Tool (DWAT)
Main Findings by Marcelo Uriburu Quirno

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 or loadable as a time series
- Very many more strengths!

Weaknesses

- The user interface is 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
- It is not possible to take advantage of the properties defined for one sub-catchment for using them for another sub-catchment to be further edited as necessary. One has to load the values one by one, even if they are the same as those for the previous sub-catchment. The possibility of copying and pasting the properties of one sub-catchment into a second one would be highly useful
- Once a time series has been created, it is not possible to edit the values if required. The corrected time series has to be created from scratch
- The information given at the bottom of the Properties window is too concise. Such a good capability could be better exploited
- Horton infiltration model is not working properly
- Routing models are not working well, except for the Muskingum model
- When manual calibration is being done, it would be convenient to have the comparison chart (Qobs vs Qsim) open for visual inspection and at the same time, to be able to modify parameters.
- For manual calibration, too many repetitive steps. It would be good if the software memorizes the last text / number insertions.

ON THE MANUAL

My comments on the manual are mostly based on the July 2018 version, the one received when the review was commissioned. During the workshop, I received a newer version (September 2018) which looks much more elaborated and with a higher degree of detail, although I haven't had the opportunity to read it completely. This means that the weaknesses identified in the July 2018 version may be no longer valid.

Strengths

- Well structured
- Easily readable
- High quality images, with excellent resolution

Weaknesses

- It would be good if different examples of model use are explicitly listed, more specifically than just saying that the model is for water resources management
- Too concise
- More examples of use would be useful
- As it is found in user manuals of other models (e.g. EPA SWMM) it is very useful to have a chapter devoted to show a step by step simple application, i.e. a quick start tutorial. In this way, the user is quickly running the model successfully, even if it is in a very simple case.

ANNEX 4

Comments on the DWAT by Mr John Fenwick

In New Zealand, difficulties were encountered getting DWAT to either complete the GIS pre-processing and/or run the model. It appeared that if there were slight differences in how data were introduced or what the sequences were, then DWAT would crash (giving the “DWAT has stopped working” message, and then restarting.
This was tried by two different people on their respective computers with similar results. At the workshop, I was still unable to run the NZ catchment data or the Korean Boryeong data on my computer, but was able to on another computer borrowed from Sung Kim. I was able to copy the result files back to my computer and display the results and calibrate, etc.
(My computer runs Windows 7 Ent, and I will shortly upgrade to Windows 10, and try this change.)
Some of the issues experienced in operation were:

- The NZ DEM would not load correctly and Dr Jang identified that there were sinks and depressions in it. Using the Hydrosheds DEM solved this, but we were surprised about the sinks as the NZ DEM had worked for other models.
- Pasting in the series data one column at a time seemed to result in the data and time sequences becoming corrupt (interval reverting to 0 min). The remedy was to set up the climate fields to match the spreadsheet (or vice versa) and paste them all in at once.
- Editing in Series View was attempted, but did not seem to work as suggested in the manual.
- DWAT crashing on exit from the Soils or Landuse tabs of the GIS Preprocessor. On some occasions this would not happen, but trying to Run would make it crash.
- After crashing, it appeared that all the GIS configuration would need to be repeated, despite files having been created.

Specific suggestions are:

- Investigate further the reasons for DWAT crashing (it happened to others besides myself) and enable easier recovery - such as enabling the GIS configurations to be re-used.
- Add soil types corresponding to bedrock and thin steepland soils.
- Consider the use of solar radiation for snowmelt.

In summary, my model results were not as good as expected but, in hindsight, trying to use an alpine catchment with a steep rainfall gradient may have been the wrong decision for this stage. The calibration abilities are valuable, and I was able to use these to advantage.
The model appears comprehensive and applicable to catchments in many of the RA V countries. I look forward to assisting in facilitating its use. The work put into development of DWAT is impressive and I congratulate and sincerely thank all those involved and our Bhutan NCMH hosts.

ANNEX 5

Comments on the DWAT by Dr Yuri Simonov

DWAT was found useful, easy to use, and having big potential for further implementation in hydrological practice from point of view of water resources assessment and other possible applications - e.g. operational flood forecasting. It was found that there are a number of deficiencies in terms of different aspects of the tool (listed below). Solving these deficiencies would significantly improve the tool.

Manual

More detailed information should be added to describe how to use different functionalities of the software. For example, it would be advantageous to allow use of different coordinate systems, as only geographic coordinate system is currently supported. The manual should better describe what meteorological input data are needed for the different approaches that could be selected (there are several options, and they have to be better described).There are many possible approaches for estimating PET and AET, so the manual should provide guidance on which approach would be preferred based on the available data types (e.g., what to do if wind, RH, and sunshine hour data are not available). More detailed guidance is needed on approaching time series generation, as different formats may have advantages over others, with these not being explained. A more detailed description on how to best approach model calibration (initial parameters value sets) is needed.

The manual should be centered on the DWAT software mainly, and the model description should be placed in an annex. This would facilitate us by developing NMHSs who will likely be more interested in first running the software.

Models

During stream flow simulation of a Russian watershed it was noticed that spring flood (induced by the seasonal snow cover melt) was not modeled in appropriate manner. It is recommended that snow dynamic routine is checked, and then tested on a basin with significant snowmelt influence. It will be also beneficial to introduce calibration of snow routine parameters against measured data (e.g. SWE, snow depth).

Software

GUI is simple and logical. So far the software has a lot of "small bugs", which should be corrected:

- every time a project is reopened a background picture is absent and needs to be reopened;
- insert a node is very simple/easy - it was done mistakenly many times during my work, make it a bit more complex (left click and then chose "add node") could be of benefit;
- when a project is saved, windows with node's properties are closed;

- project information is saved only in one file "*.dpr", however it will be beneficial if it could also have different text files, representing variables of different nodes;
- was not able to upload spatial data (e.g. DEM) - error message and project closed;
- layers menu - background layers are presented as "background", and if there are more than one layer, it is impossible to understand what layer to remove - it is better to name background layers with their original filenames;
- download background layers - more formats could be added: to open very popular .png formatted file it is necessary to choose "all formats";
- had problems with downloading observed discharge, no issues with observed climate;
- editing existing .dat files should be available (now it is necessary to create data file from scratch);
- soil moisture depth units (written m, but in reality should be in mm)

When doing manual calibration of parameters, It would be beneficial to visualize the efficiency of the new model run (within the scatter chart) at the same time as the parameters that are being calibrated, without having to re-open every time the efficiency scatter chart. Instead, the software currently makes the user close the scatter chart before modifying the parameters, with the need of doing another run.

DWAT application

It was found to be useful and has high potential. To make it more useful for developing NMHSs, it is necessary:

- to reduce the types of input meteorological data required (wind, number of sunshine hours, tmax, tmin, and RH) as some of these may be unavailable in many cases. The tool should be modified to allow its application for data sparse areas;
- to add several functionalities (e.g. needs a good data editing module, introduce discharge adjustment to allow correction based on previous time steps error (data assimilation)), ability to ingest real-time data and NWP forecast data for discharge forecasting). Such increased functionality would allow DWAT to be used operationally for flood forecasting.

DWAT was found to have simple routing techniques that are used in some other semi-distributed models, which is useful when detailed bathymetric data are not available. This is useful for both developed and developing countries.