OUWIN Chicken Creek Calibration

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# Overview

This document describes a calibration in July and August 2019 of the OUWIN model for the Chicken Creek watershed. Although the OUWIN model simulates the entire Willamette River basin, it uses distinct sets of parameter values for different watersheds within the basin. In this context, “calibration” means the process of selecting particular parameter values for a given watershed so as to minimize the difference between simulated daily flows and measured daily flows.

Papers by Moriasi and co-authors (Moriasi et al. 2007 and 2015) describe statistics which may be used to judge how skillful a hydrological model is at reproducing the observed flows. Moriasi et al. include threshold values for each of a small handful of statistics, for distinguishing different levels of model performance as “very good”, “good”, “satisfactory”, or “not satisfactory”.

At first the OUWIN model used parameter values inherited from the WW2100 model. The OUWIN model, like the earlier WW2100 model, reproduced flows reasonably well at a monthly timestep, but poorly at a daily timestep. The model has since been recalibrated to improve its skill at the daily timestep (Table 1).

Table 1. Model skill statistics for the Chicken Creek watershed for the calibration period, 2009-15.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **statistic, after Moriasi et al 2007 and 2015** | **original monthly** | **new monthly** |  | **original daily** | **new daily** |
| coefficient of determination (R2) | 0.963 VG | 0.949 VG |  | 0.51 NS | 0.801 G |
| Nash-Sutcliffe efficiency (NSE) | 0.962 VG | 0.947 VG |  | 0.44 NS | 0.798 G |
| percent bias (PBIAS) | 2.65% VG | 2.66% VG |  | 2.60% VG | 5.31% G |
| RMSE:observations std. dev. ratio (RSR) | 0.19 VG | 0.23 VG |  | 0.75 NS | 0.48 VG |

Note: VG = good, G= good, S = satisfactory, NS = not satisfactory. Original statistics are for calendar years 2009-15. New statistics are for water years 2009-15.

# HBV parameters

OUWIN uses a variant of the HBV precipitation-runoff model (Seibert 1997). The OUWIN version of HBV has 12 parameters (Table 2). In the Chicken Creek calibration, 4 parameters were fixed (TT, CFMAX, CFR, and WP) and 8 parameters were calibrated (FC, BETA, PERC, UZL, K0, K1, K2, and ET\_MULT). Three (TT, CFMAX, CFR) of the four fixed parameters relate to proportions of snow v. rain. Since snow seldom falls in the Chicken Creek watershed, these three parameters have little effect on the model’s skill; plausible fixed values were set, taken from previous work with the WW2100 model. The model is also relatively insensitive to the wilting point parameter WP, so WP was fixed at a widely used value from the literature. The K2 parameter was first determined by the automated method described below, then adjusted manually to improve model skill during low flow periods.

All but one of the 8 calibrated parameters are present in other versions of HBV. The ET\_MULT parameter is not; it was added in the OUWIN project to adjust for uncertainty in the gross amount of vegetation in the watershed. Chicken Creek is a mixture of urban, agricultural, and forest lands. The evapotranspiration (ET) term in the water budget is largely driven by the fraction of forest lands and the leaf area of the forests, but those values are poorly known. ET\_MULT is a simple multiplier on the simulated amount of ET from the forest lands. Forest ET is estimated using the Penman-Monteith equation, outside of the HBV module.

Table 2. HBV parameters in OUWIN

|  |  |  |  |
| --- | --- | --- | --- |
| **parameter** | **origin** | **units** | **method** |
| TT refreezing threshold | std HBV | °C | fixed |
| CFMAX melt rate | std HBV | mm SWE per °C | fixed |
| CFR refreezing coefficient | std HBV | mm H2O per °C | fixed |
| FC field capacity | std HBV | mm H2O | calibrated |
| BETA recharge exponent | std HBV | dimensionless | calibrated |
| PERC percolation fraction | std HBV | dimensionless | calibrated |
| UZL fast drain threshold | std HBV | mm H2O | calibrated |
| K0 fast drain fraction | std HBV | dimensionless | calibrated |
| K1 intermediate drain fraction | std HBV | dimensionless | calibrated |
| K2 slow drain fraction | std HBV | dimensionless | manually set |
| WP wilting point | std HBV | mm H2O | fixed |
| ET\_MULT evapotranspiration multiplier | new in OUWIN | dimensionless | calibrated |

### TT, refreezing threshold temperature (fixed at 0.0 °C)

TT is the temperature in °C below which the water in the snowpack begins to refreeze.

### CFMAX, melt rate (fixed at 6 mm SWE per day per °C)

CFMAX is the amount of snow, measured as mm of SWE, which will melt per day per °C above 0 °C.

### CFR, refreezing coefficient (fixed at 0.06852 mm H2O per day per °C)

When the temperature is below the snow threshold, some water in the snowpack may refreeze. The amount of water which could refreeze, in mm, is CFR\*CFMAX per day per °C below the snow threshold.

### FC, field capacity of the topsoil

In HBV, FC is used in calculating the groundwater recharge fraction, which is the fraction of the incoming rain and snowmelt which bypasses the topsoil and goes directly to the subsoil. The groundwater recharge fraction is calculated as the amount of water currently in the topsoil (to be exact, the amount above 10 mm, taken as the wilting point), expressed as a fraction of FC, raised to the power BETA. When the topsoil is already at field capacity, all the incoming water bypasses the topsoil and recharges the subsoil. In OUWIN’s evapotranspiration submodel, FC is used in the calculation of the soil water threshold at which transpiration begins to shut down due to lack of soil water. The threshold is calculated as

0.5\*(FC - 10 mm).

### BETA, recharge exponent

BETA is used to calculate the groundwater recharge fraction. See the description under FC above.

### PERC, percolation fraction

PERC is the fraction of the water in the subsoil pool which percolates down to the groundwater pool each day.

### UZL, fast drain threshold

UZL is a soil water threshold value in mm which is used in the decision about which of two forms of the q0 calculation to use. q0 is the amount of water that flows from the subsoil to the stream each day. When the water content of the subsoil is above UZL, q0 is calculated as

K0\*(subsoil water content - UZL) + K1\*subsoil water content

When the water in the subsoil is at or below UZL, q0 is just

K1\*subsoil water content

Note that sets of PERC, UZL, K0, and K1, which result in more water flowing out of the subsoil pool than there is in the pool to start with, are non-physical. The Q0() procedure returns a value which is never more than the amount that was in subsoil at the beginning of the day. When the percolation amount plus q0 exceed the starting amount in the subsoil plus the groundwater recharge, the percolation amount is reduced accordingly, i.e. water flows to the stream before it percolates downwards.

### K0, fast drain fraction

K0 is dimensionless, and is used in the calculation of q0, the water which flows from the subsoil to the stream. See the description under UZL.

### K1, intermediate drain fraction

K1 is dimensionless, and is used in the calculation of q0, the water which flows from the subsoil to the stream. See the description under UZL.

### K2, slow drain fraction

K2 is dimensionless, and is the fraction of the groundwater pool which flows to the stream each day. The value of K2 produced by PEST was 0.0706. K2 was subsequently set to 0.0200 manually, to improve the skill of the model at low flows.

### WP, soil water content at the permanent wilting point (fixed at 10 mm H2O)

10 mm H2O per meter of soil is used an approximation of the soil water content when the soil water potential is at the permanent wilting point, -1.5 kPa.

### ET\_MULT, evapotranspiration multiplier

ET\_MULT is dimensionless, and is a multiplier applied to the calculated daily evapotranspiration to achieve as little bias as possible in the daily streamflow.

# Use of PEST

We used a parameter estimation program, PEST ([www.pesthomepage.org](file:///C:\Envision\StudyAreas\WW2100\Docs\CalibrationWriteup\www.pesthomepage.org)), to identify sets of the 8 calibrated parameter values which produce good correlations between streamflows simulated by OUWIN and stream gage readings supplied by Clean Water Services, the municipal water utility which serves the Chicken Creek area. Our use of PEST for OUWIN is based on the work with PEST that was done for the WW2100 project, originally by Eric Watson and Yeejun Chang at Portland State University in 2015, and subsequently by Oregon Freshwater Simulations in 2016 (Conklin 2016).

PEST works by selecting a set of parameter values, running the OUWIN model, and calculating a value (the “objective function”) representing the divergence of the simulation results from the gage readings. This process is repeated with different sets of parameter values in a systematic exploration of the parameter space. The process terminates when successive adjustments to the parameter values fail to reduce the divergence by a specified amount. The model may exhibit equifinality: different sets of parameter values may produce equally good simulation results.

Starting parameter values were set equal to those for Chicken Creek in the original OUWIN HBV parameter set. Valid ranges were estimated based on other publications of research using HBV (Abebe et al. 2010, Aghakoouchak & Habib 2010, Inouye 2015, Steele-Dunne et al 2008). Table 3 shows the starting values, ranges, and final calibrated values.

Table 3. OUWIN HBV parameter valid ranges, starting values, and final values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **parameter** | **units** | **valid range** | **starting value** | **final value** |
| TT refreezing threshold | °C | fixed at 0.0 | 0.0 | 0.0, fixed |
| CFMAX melt rate | mm SWE per °C | fixed at 6.0 | 5.774 | 6.0, fixed |
| CFR refreezing coefficient | mm H2O per °C | fixed at 0.06852 | 0.026 | 0.06852, fixed |
| FC field capacity | mm H2O | 50 - 550 | 270.912 | 332.8479 |
| BETA recharge exponent | dimensionless | 1 - 6 | 3.075 | 3.177116 |
| PERC percolation fraction | dimensionless | 0.01 – 0.20 | 0.179 | 0.2 |
| UZL fast drain threshold | mm H2O | 0 - 80 | 0.211 | 8.652508 |
| K0 fast drain fraction | dimensionless | 0.1 – 0.6 | 0.598 | 0.6 |
| K1 intermediate drain fraction | dimensionless | 0.01 – 0.30 | 0.298 | 0.12632 |
| K2 slow drain fraction | dimensionless | 0.0 – 0.1 | 0.001 | 0.02 set manually |
| WP wilting point | mm H2O | fixed at 10 | 10 | 10, fixed |
| ET\_MULT evapotranspiration multiplier | dimensionless | 0.5 – 2.0 | 1.0 | 0.812516 |

The objective function was the sum of weighted squared differences, in cms2, between simulated daily flows and observed daily flows for the 7 water years 2009-15. The time series of observed daily flows included a small proportion of estimated values, but mostly represented measurements by a stream gage on Chicken Creek near Roy Rogers Road (USGS gage #14206750), on the reach identified in the National Hydrography dataset as COMID 23805228. The observed flow time series was provided in cfs units by Clean Water Services.

There was one outlier value in the time series of observed daily flows, an estimated value for 1/2/2009 of 713 cfs, about 300 cfs higher than any other daily value in the 7-year series. This outlier was treated as a typographical error, and changed to 71 cfs.

The OUWIN simulation used GridMet daily meteorological data downloaded from the MACA website at the University of Idaho in March, 2019, by Oregon Freshwater Simulations. The OUWIN model was run for the 8 calendar years 2008-15 in order to obtain output data for the 7 water years 2009-15 (10/1/2008 – 9/30/2015). Data for days outside the 7 water years was given a weight of 0 in the calculation of the objective function, while data for days in the water years was given a weight of 1. Daily data and simulations for this calibration included leap days 2/29/2008 and 2/29/2012. Earlier OUWIN and WW2100 calibrations used uniform length 365-day years without leap days.

The OUWIN model was run with the SWMM-lite, forest growth, and irrigation decision processes turned on, but with crop choice, wildfire, DGVM vegetation change, land use transition, and urban expansion processes turned off.

# Results

The results from using the PEST program were good, improving the daily timestep statistics substantially. Examination of the daily simulated flows brought to light large proportional differences between measured and simulated flows during periods of low flow. The value for K2 was changed from the PEST output value, 0.070597, to 0.02, to improve the model’s skill at low flows. This change had only a small effect on the numerical value of the skill statistics.

Observation data for the years 2003-07 was available, but was held back from the calibration process so that it could be used for validation. Final Moriasi skill statistics for both the calibration and validation periods are given in Table 4.

Table 4. Final model skill statistics for the calibration and validation periods

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **statistic, after Moriasi et al 2007 and 2015** | **monthly, calibration** | **monthly, validation** |  | **daily, calibration** | **daily, validation** |
| coefficient of determination (R2) | 0.95 VG | 0.96 VG |  | 0.79 G | 0.83 G |
| Nash-Sutcliffe efficiency (NSE) | 0.96 VG | 0.94 VG |  | 0.79 G | 0.81 G |
| percent bias (PBIAS) | 2.7% VG | 7.0% G |  | 1.9% VG | 6.5% VG |
| RMSE:observations std. dev. ratio (RSR) | 0.23 VG | 0.24 VG |  | 0.46 VG | 0.43 VG |

Note: VG = good, G= good, S = satisfactory, NS = not satisfactory. Calibration statistics are for water years 2009-15. Validation statistics are for water years 2003-07.

It may be possible to increase the model’s skill, as measured by the numerical values of the Moriasi statistics, still further. Newly available observation data for years after 2015 could be used to extend the calibration period. The outlier on 1/2/09 could be treated differently. Estimated values in the observations could be given a zero weight. Different parameter starting values or valid ranges could be used for the PEST execution. The calibrated values of PERC and K0, in particular are pegged at the upper end of their respective ranges; allowing PEST to pick somewhat larger values for PERC and K0 could conceivably produce a better model fit. However, given that the qualitative Moriasi ratings are already “very good” or “good”, the room for qualitative improvement is limited.

The manual adjustment of the K2 parameter value was made in recognition of the importance of the low flows to the OUWIN research objectives, and with a realization that the exact value of K2 as it nears zero has little impact on the overall Moriasi skill statistics. There are several other ways in which the low flows could be given more importance in the calibration process:

- in PEST, the weights associated with low flow observations could be increased relative to the weights for higher flow observations

- the objective function itself could be changed (e.g. use NSE, or the absolute value of the residuals when summing instead of the squared value of the residuals)

- all the individual predicted and observed values could be transformed (e.g. logarithms of the predicted and observed values could be taken) before they are input to PEST to compute residuals

- the entire time series of predictions and observations could be converted into series of statistics (e.g. into series of 7-day low flow values), before they are input to PEST.

OUWIN’s simulation of streamflow goes beyond the HBV precipitation-runoff model to include simulated irrigation and municipal withdrawals from streams, and simulated municipal discharges to streams. Additions to the surface water budget from groundwater pumping for irrigation are also included. The Chicken Creek area gets its municipal water from outside the Chicken Creek watershed, and returns treated sewer water to the Tualatin river at a location outside the Chicken Creek watershed, so the effect of municipal water usage on the flows in Chicken Creek itself is limited to runoff from outdoor water use supplied from city water (e.g. lawn sprinklers). Outdoor use of city water is simulated using seasonality data from the Portland Water Bureau; it is a relatively small part of the overall water budget for the watershed. It is plausible that records of municipal water usage could be obtained from the local water utility, Clean Water Services. Agricultural irrigation is also simulated, but records of actual irrigation are not available.

The additional information in records of municipal water usage could be used to improve the Chicken Creek streamflow calibration in several ways. First, records of actual municipal water usage could be substituted for simulation of municipal water usage, to better constrain the input to the streams from outdoor use of city water. Then the PEST calibration could be rerun. Second, one or more parameters of the urban water module could be added to the parameter space explored by PEST in the flow calibration, analogous to the addition of the ET\_MULT parameter. Third, a multiple objective calibration (Gupta et al. 1998) could be done by including an objective function which relates actual municipal water usage to simulated usage, with the present one relating measured flows to observed flows.

# Glossary of acronyms

**BETA** – recharge exponent, an HBV parameter

**CFMAX** – melt rate, an HBV parameter

**CFR** – refreezing coefficient, an HBV parameter

**cfs** – cubic feet per second

**cms** – cubic meters per second

**DGVM** – dynamic global vegetation model

**ET** – evapotranspiration

**ET\_MULT** – evapotranspiration multiplier, an HBV parameter

**FC** – field capacity, an HBV parameter

**HBV** – the Hydrologiska Byråns Vattenbalansavdelning hydrology model

**HBVCALIB** – an identifier for the set of HBV parameter values used in a particular part of the study area

**K0** – fast drain fraction, an HBV parameter

**K1** – intermediate drain fraction, an HBV parameter

**K2**  - slow drain fraction, an HBV parameter

**MACA** – Multivariate Adaptive Constructed Analogs

**OSU** – Oregon State University

**OUWIN** – Oregon Urban Water Innovation Network

**PERC** – percolation fraction, an HBV parameter

**PEST** – Model-Independent Parameter Estimation and Uncertainty Analysis software application ([www.pesthomepage.org](file:///C:\Envision\StudyAreas\WW2100\Docs\CalibrationWriteup\www.pesthomepage.org))

**SWE** – snow water equivalent

**TT** – refreezing threshold temperature, an HBV parameter

**UZL** – fast drain threshold, an HBV parameter

**WP** – wilting point, an HBV parameter

**WRB** - Willamette River basin

**WW2100** – Willamette Water 2100

# References

Abebe NA, Ogden FL, Pradhan NR (2010). Sensitivity and uncertainty analysis of the conceptual HBV rainfall-runoff model: Implications for parameter estimation. Journal of Hydrology 389: 301-310.

Aghakouchak A, Habib E (2010). Application of a Conceptual Hydrologic Model in Teaching Hydrologic Processes. Int. J. Engng Ed. 26(4): 963-973.

Gupta HV, Sorooshian S, Yapo PO (1998). Toward improved calibration of hydrologic models: Multiple and noncommensurable measures of information. Water Resources Research 34 (4): 751-763, April 1998.

Inouye AM (2015). Development of a Hydrologic Model to Explore Impacts of Climate Change on Water Resources in the Big Wood Basin, Idaho. M.S. thesis, Oregon State University.

Conklin DR (2016). WW2100 HBV Parameter Calibration. Oregon Freshwater Simulations, 9/15/16, unpublished. 22 pages. Available in the WW2100 Subversion repository at <https://freshwater.ceoas.oregonstate.edu:8443/svn/WW2100svn/trunk/StudyAreas/WW2100/Docs>

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, and Veith TL (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, 50(3): 885-900.

Moriasi DN, Gitau MW, Pai N, Daggupati P (2015). Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. Transactions of the ASABE, 58(6): 1763-1785.

Seibert J (1997). Estimation of Parameter Uncertainty in the HBV Model. Nordic Hydrology, 28 (4/5): 247-262.

Steele-Dunne S, Lynch P, McGrath R, Semmler T, Wang S, Hanafin J, Nolan P (2008). The impacts of climate change on hydrology in Ireland. Journal of Hydrology 356: 28-45.