CW3M Digital Handbook

Information about the Community Willamette Whole Watershed Model

9/12/20

CW3M is maintained by Oregon Freshwater Simulations Inc.

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Changes since the 8/14/20 version

- Collect the information about the representation of stream flow and stream temperature into a single chapter called “Stream flow and stream temperature”

- In the “Stream flow…” chapter, add sections “Boundary conditions for stream water temperature”, “Thermal loading”, and “Thermal stratification in reservoirs”

- In the “McKenzie Basin…” chapter, add subsection “Data changes for better representation of wetlands”

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# What is a digital handbook?

We intend the digital handbook to collect all our information about CW3M in a single place. “CW3MdigitalHandbook” is the name of a folder on a Windows file system which contains multiple files, including the MS Word file of this document (CW3MdigitalHandbook.docx) and an accompanying Excel file (CW3Mhandbook.xlsx).

# CW3M concept

## A different kind of community model

CW3M stands for Community Willamette Whole Watershed Model. The “Willamette Whole Watershed Model” part is a generic term for the series of whole watershed models developed by the WW2100, OUWIN, and Willamette INFEWs projects. The “Community” part is inspired by the community models maintained by the National Center for Atmospheric Research: the Community Earth System Model (CESM), and the Whole Atmosphere Community Climate Model (WACCM). NCAR’s “Community” is the community of scientists who develop and use the NCAR models. The “Community” in CW3M is made up of the analogous group of scientists from the research projects, but includes also the community of policy makers, land managers, reservoir operators, NGOs, government agencies, utility operators, farmers, and others who can make use of the model outputs - the stakeholder community. CW3M is for that larger community. It retains, however, some of the key features of NCAR’s community models: open access to source code, the opportunity for qualified people to contribute to model development and data, and rigorous version control.

## What CW3M is for

The intent for CW3M is to flesh out the Willamette basin regional results with more details at the scale of the Willamette's tributary rivers. As of mid 2020, model data files have been set up for 13 study areas: the entire Willamette basin; the smaller basins drained by the Clackamas, Long Tom, Luckiamute, Marys, McKenzie, Molalla, North Santiam, Pudding, and Tualatin rivers; the Chicken Creek watershed in the Tualatin basin; and the upper Willamette basin, composed of the areas drained by the Coast Fork, the Middle Fork, and the McKenzie rivers. Ultimately CW3M would include detailed models of all the major subregions in the Willamette River basin.

A second objective of the CW3M project is to improve the model's skill through reconciliation with available independent datasets. This is a continuation of work already started at the regional scale, comparing simulated streamflows with USGS gage records for the actual weather of recent decades; results of that work were reported at the 2018 NW Scientific Association conference. This effort is expected to improve the calibration of many of the constituent submodels: not just streamflow but also urban water use, irrigation, population, crop choice, land use change, expansion of urban growth areas, and so on. Opportunities for better calibration increase as the spatial focus narrows from the whole WRB to tributary subbasins.

The goal is to produce an open source model and an accompanying collection of datasets which are useful to agencies and organizations involved in planning and management of lands in the Willamette River basin, especially in the context of the stresses and uncertainties arising from climate change and population growth. The model, if successful, will provide process-based and data-driven conjectures in response to some of the essential what-if questions.

## Management and maintenance

Unlike for NCAR’s community models, there is no large organization behind CW3M. A CW3M Steering Committee has been set up and is composed of 8 individuals who have agreed to a memorandum of understanding (MOU). The text of the MOU is a separate file in the digital handbook. The steering committee meets quarterly over the Internet. Rebecca McCoun is the current steering committee chairperson. She can be reached by email at northsantiamwc@gmail.com.

As of mid-2020, Oregon Freshwater Simulations (Freshwater) is continuing as the “principal developer” of CW3M, a role described in the MOU. Freshwater is a tiny consultancy in Portland. It was the keeper of the Envision-based models for the WW2100 and OUWIN project, and for the initial years of the Willamette INFEWS project, acting as a vendor to Oregon State University.

# Study areas

As of mid-2020, CW3M simulations can be executed for 13 watersheds:

Willamette River (Figure 1)

Tualatin River (Figure 2)

Chicken Creek (part of the Tualatin basin; Figure 5)

North Santiam River (Figure 3)

the upper Willamette basin (McKenzie + Middle Fork + Coast Fork; Figure 4)

Calapooia River

Clackamas River

Long Tom River

Luckiamute River

Marys River

McKenzie River

Molalla River

Pudding River

## DataCW3M directory structure

Installation of CW3M using a turnkey installer package such as CW3M\_0.1.4\_Installer.exe will result in the creation of a folder, e.g. “C:\DataCW3M\_0.1.4”, containing the data files necessary for execution of the “Demo” scenario by the model. The data folder contains the ENVX files for all the study areas, a subdirectory for each study area, and in addition some other files and folders common to all the study areas.

Within the data directory, for each study area there is an ENVX file which specifies how to carry out the simulation of the particular study area, and a folder containing input and output files pertaining to the particular study area. For example, C:\DataCW3M\_1.0.0 may contain these files and folders:

Folders

Calapooia

ChickenCreek

Clackamas

CW3MdigitalHandbook

GriddedRecentWeather

LongTom

Luckiamute

Marys

McKenzie

Molalla

NSantiam

Observations

Pudding

Reservoirs

ScenarioData

Tualatin

UpperWRB

Files

CW3M\_Calapooia.envx

CW3M\_ChickenCreek.envx

…

CW3M\_WRB.envx

## DataCW3M\ScenarioData directory structure

The ScenarioData directory contains folders for each scenario and some files which are common to multiple scenarios:

Folders for each scenario

Baseline

Demo

Files common to multiple scenarios

APs.xml

cooling\_cost.csv

cropchoice.csv

Crops.csv

deterministic\_transition\_lookup.csv

HBV.csv

HRU.xml

IDU.xml

Reach.xml

Reporter.xml

SpatialAllocator.xml

VegSTM.xml

wr\_pods.csv

wr\_pous.csv

## DataCW3M\ScenarioData\<scenario> folder contents

Scenario folders contain data files which are specific to individual scenarios.

## DataCW3M\<study area> folder contents

The folder for a particular study area contains the IDU, HRU, and Reach shapefiles for that study area and may contain other folders and files specific to the study area. Generally, a file specific to a study area will use the study area name as a suffix, e.g. Flow\_NSantiam.xml. The suffix comes before the file type.

## 

![A close up of a map

Description automatically generated]()

Figure 1. Willamette River basin study area; embedded study areas are colored other than gray. The 2 lighter blues together make up the upper Willamette basin study area.

![A screenshot of a video game

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Figure 2. Tualatin basin study area; Chicken Creek watershed is highlighted.

![A picture containing screenshot

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Figure 3. North Santiam watershed study area.

![A screenshot of a map

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Figure 4. Upper Willamette study area.

![A close up of a map

Description automatically generated]()

Figure 5. Chicken Creek watershed study area.

# Calendar conventions

CW3M supports the standard calendar with leap years, and in addition supports a calendar consisting of uniform 365-day years with no leap years or leap days. The uniform 365-day calendar convention is included as an option for compatibility with older climate datasets lacking leapdays.

CW3M defaults to the standard calendar. The uniform 365-day option can be invoked by including

maxDaysInYear='365'

in the <settings> block of the ENVX file. The default setting is

maxDaysInYear='366'

Hadley Climate Center in the U.K. produced climate datasets with uniform 360-day years in the past, but has now switched to more standard calendar conventions. Hadley’s 360-day climate datasets are not supported by CW3M.

For debugging purposes, CW3M allows maxDaysInYear to be set to 1 or 0.

## Water years

CW3M supports reporting some output data on a water year basis, instead of a calendar year basis. Water years start on October 1st and end on September 30th; they are named the same as the calendar year in which they end.

Reporting by water year is controlled by a field in the <settings> block of the ENVX file:

useWaterYears='1'

The default setting is

useWaterYears='0'

Reports specified in the Flow XML file are affected by the useWaterYears setting.

# Climate data

## Numbered climate scenarios in the model

The Flow.xml file contains a numbered list of climate datasets available within the model. As of April 2019, the list has 9 entries which are consistent with the corresponding lists in the WW2100, OUWIN, and CW3M projects. Table identifies the numbered climate scenarios.

We expect to add additional climate datasets to the list, drawn from **Error! Reference source not found.**, when the data has been converted from gridded form to the IDU-centric form preferred in the INFEWS model.

Table 1. Numbered climate scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| climate scenario number | date range | name; source of data | project, simulation scenario first used for |
| 0 | 1950-2100 | MIROC; MIROC5 from MACA v1 | WW2100 Reference |
| 1 | 1950-2100 | GFDL; MACA v1 | WW2100 LowClim |
| 2 | 1950-2099 | HadGEM; MACA v1 | WW2100 HighClim |
| 3 | 1950-2100 | WW2100StationaryClimate; MIROC5 from MACA v1 | WW2100 Stationary Climate |
| 4 | 1979-2011 | MACAtrainingData; MACA v1 | WW2100 PEST |
| 5 | 2000-2017 | BaselineGrid; MACA training data | INFEWS development |
| 6 | 2000-2017 | BaselinePoly; BaselineGrid interpolated to IDU centroids by SnowModel | INFEWS Baseline |
| 7 | 2010-2017 | GriddedRecentWeatherForDemos; subset of BaselineGrid | INFEWS Demo |
| 8 | 1979-2018 | BaselineGridMultiyearFiles; gridMET | CW3M Baseline |
| 9 | 1950-2005 | MIROC5\_macav2; macav2metdata MIROC5 r1i1p1 20th century | CW3M MIROC5\_20th\_century |
| 10 | 2006-2099 | MIROC5\_rcp85; macav2metdata  MIROC5\_r1i1p1\_rcp85 | CW3M MIROC5\_rcp85 |
| 11 | 1950-2005 | HadGEM2-ES\_macav2; HadGEM2-ES365\_r1i1p1\_20th century | CW3M HadGEM-ES\_20th\_century |
| 12 | 2006-2099 | HadGEM2-ES\_rcp85; macav2metdata\_HadGEM2-ES365\_r1i1p1\_rcp85 | CW3M HadGEM-ES\_rcp85 |

## Monthly and seasonal weather data

Several model components pertaining to the agricultural basin use monthly and seasonal weather data (e.g. crop choice and farm rent). The monthly and seasonal weather values are aggregated up from the daily weather values in the input climate dataset. The monthly and seasonal weather values are held as IDU attributes.

There are 7 attributes which represent values for months or seasons in the current year: TMIN\_GROW, PRCP\_GROW, PRCPWINTER, PRCPSPRING, PRCP\_JUN, PRCP\_JUL, PRCP\_AUG. For these calculations, the growing season is defined as April through October. Winter is January through March, and spring is April through June.

There are 5 attributes which represent multi-year averages: TMINGROAVG, PRCPGROAVG, PRCPJUNAVG, PRCPJULAVG, PRCPAUGAVG. Multi-year averages are calculated using exponential averaging:

multi-year avg. = prev. avg. \* e-1/tau + curr. yr. \* (1 – e-1/tau)

where tau defaults to 10 but can be specified in the ENVX file with the tag, “yearsInStartingClimateAverages” in the <settings> block.

The initial condition previous average values used at the beginning of simulation in the exponential average calculation are themselves calculated when the simulation is run for zero years (i.e. in the FlowModel::InitRun() subroutine), using climate data for the “tau” number of years just prior to the “reference start year”. The reference start year defaults to 2010, but can be set explicitly using the “referenceStartYear” tag in the <settings> block of the ENVX file.

There is no explicit definition of the boundaries of the agricultural basin. The monthly and seasonal weather data is calculated for the entire study area.

## Climate data grids

The climate data grid has a lattice spacing of 2’ 30” of arc in both latitude and longitude. It consists of 54 columns from west to east, and 66 rows from south to north. Two slightly different versions of this grid have been used. Climate scenarios 0 through 7 use climate datasets from the WW2100 project, structured in many relatively small NetCDF files each containing daily data for a single climate field for a single year, e.g. daily precipitation for 2010. Climate scenarios 8 through 12 use “v2” datasets, structured in a small number of much larger NetCDF files each containing data for a single climate field for a range of years, e.g. daily precipitation for the years 2006-2099.

Note that, although the climate grid is in units arc (degrees of latitude and longitude), the GIS layers (IDU, HRU, and Reach shapefiles) use UTM Zone 10N coordinates in units of distance (meters).

### The WW2100 climate grid

The WW2100 grid locates the row 0, column 0 gridcell in the northwest corner of the grid. In the WW2100 grid, the centers of the corner grid cells are located at

center of northwest corner gridcell 46 deg 01’ 15” N, 123 deg 48’ 45” W

center of southwest corner gridcell 43 deg 18’ 45” N, 123 deg 48’ 45” W

center of northeast corner gridcell 46 deg 01’ 15” N, 121 deg 36’ 15” W

center of southeast corner gridcell 43 deg 18’ 45” N, 121 deg 36’ 15” W

Data for each day begins with the data for the NW gridcell, designated as row 0, column 0, the grid origin. Column numbers increase from west to east, from 0 through 53, before the row number increases from 0 to 1. Row numbers increase from north to south.

This WW2100 grid is a subgrid of a grid whose southern edge is the equator, northern “edge” is 90 deg N, eastern edge is 0 deg of longitude, and western edge is at 180 deg of longitude. The edges of the subgrid are located at:

northern edge 46 deg 02’ 30” N

southern edge 43 deg 17’ 30” N

eastern edge 121 deg 35’ 00” W

western edge 123 deg 50’ 00” W

### The v2 climate grid

The v2 grid locates the row 0, column 0 gridcell in the southwest corner of the grid, and is offset from the WW2100 grid by 15 arc-seconds to the north and 15 arc-seconds to the east. In the v2 grid, the centers of the corner grid cells are located at

center of northwest corner gridcell 46 deg 01’ 30” N, 123 deg 48’ 30” W

center of southwest corner gridcell 43 deg 19’ 00” N, 123 deg 48’ 30” W

center of northeast corner gridcell 46 deg 01’ 30” N, 121 deg 36’ 00” W

center of southeast corner gridcell 43 deg 19’ 00” N, 121 deg 36’ 00” W

Data for each day begins with the data for the SW gridcell, designated as row 0, column 0, the grid origin. Column numbers increase from west to east, from 0 through 53, before the row number increases from 0 to 1. Row numbers increase from south to north.

## How climate data is looked up

Each IDU is associated with the climate grid cell in which the IDU’s centroid is located, and similarly with HRUs. The IDU layer has an attribute named GRID\_INDEX which identifies the climate grid cell associated with the IDU polygon. The IDU, HRU, and Reach layers all have attributes for the weather fields: precipitation, tmin, tmax, humidity, etc. Data is read from the gridded climate data files in each daily time step and used to populate the IDU attributes for the weather fields. The HRU weather field values are the area-weighted averages of the IDUs in the HRU. The Reach weather fields are the values for the IDU which contains the reach’s vertex 0, the upstream end of the reach.

C++ methods involved in looking up climate data include:

FlowModel::OpenClimateDataFiles(year), called at the beginning of each simulated year

FlowModel::GetDailyWeatherField(day, year, field)

ClimateDataInfo::GetTimeIndex(day, year) calculates the location in the file of the day’s data

FlowModel::InitClimateMeanValues(), called in InitRun(), but only when yearsToRun = 0.

## What is in a climate dataset

Climate data is supplied at a temporal resolution of 1 day. The spatial resolution is one climate grid cell. An alternative spatial resolution of IDU polygons is also available; it requires preprocessing the gridded climate data to interpolate spatially to IDU centroids. The required and optional weather fields are identified below. Within parentheses, common field variable names are shown in lower case, and associated attribute names are shown in upper case.

These fields are required:

daily precipitation, mm H2O (pr, precip, PRECIP)

diurnal minimum temperature, deg C or deg K (tasmin, tmin, TMIN)

diurnal maximum temperature, deg C or deg K (tasmax, tmax, TMAX)

solar radiation, W/m2 (rsds, solrad, RAD\_SW)

Humidity is also required, but can be supplied either as

specific humidity, kg H2O/kg air (sph, humidity, SPHUMIDITY)

or

relative humidity, %

If both are supplied, specific humidity is used. As of May 2019, the ability to use relative humidity climate data instead of specific humidity data has not yet been implemented.

Relative humidity may be supplied either as a daily value or as diurnal extremes:

diurnal minimum relative humidity, % (rhmin)

diurnal maximum relative humidty, % (rhmax)

Daily mean temperature may either be supplied

daily mean temperature, deg C or deg K (TEMP)

If daily mean temperature is not supplied, then it is calculated as needed as the average of the diurnal extreme temperatures.

Windspeed is used, but if not supplied is set to a constant 1 m/s. Windspeed may be supplied directly as

windspeed, m/s (ws, windspd, WINDSPEED)

or may be calculated as needed from the components of the wind vector if they are supplied:

eastward wind, m/s (uas)

northward wind, m/s (vas)

# Water rights

## Water rights data

The water rights module reads two .csv files at initialization. One, wr\_pods.csv, is a list of points of diversion (PODs). The other, wr\_pous.csv, is a list of points of use (POUs). These files were created for the WW2100 project in the summer of 2015 by Andrea Laliberte, a consultant working for Bill Jaeger (OSU Applied Economics Dept.). The OWRD water rights database is the original source data from which the POD and POU files were derived. A number of small changes have been made to the files since to improve their accuracy and correct typos.

CW3M assumes that the watermaster will never cut off a municipal water supply. To track events which might otherwise lead to cutting of a municipal water supply, imaginary backup water rights for municipal water systems in the 8 largest urban growth areas (Metro, Eugene-Springfield, Salem-Keiser, Corvallis-Philomath, Albany, Newberg, Woodburn) are represented in the wr\_pods.csv file. These rights have WATERRIGHTID values of >= 200000 and PODRATE value of 1000 cfs, with priority dates of 1/1/2010. Use of these backup water rights is recorded in the “ALTWM Annual Muni Backup Water Right Use” report.

## The wr\_pods.csv file

wr\_pods.csv is a comma-separated-values text file with the columns listed below. The model code requires the file to be sorted in order of priority date, from earliest date to latest date. During the simulation, rights having priority dates later than the current simulation date are ignored. For code values in the PERMITCODE, USECODE, AND SPECIAL columns, see the “Water Right Code Values” tab in CW3Mhandbook.xlsx.

WATERRIGHTID – “WaterRightId” in OWRD’s Water Right Information System

X – easting of point of diversion

Y – northing of point of diversion

PODID – point of diversion ID number assigned by CW3M

POUID – if > 0, ID number of point of use of water from this point of diversion; if < 0 and > -99, water from this point of diversion is used in a municipal water system, and the absolute value of POD is the urban growth area ID number; if = -99, this is an instream water right.

PERMITCODE – code for type of diversion (surface water, ground water, …)

PODRATE – maximum diversion rate, cfs

USECODE – code for type of use (municipal, irrigation, instream, …)

PRIORITYDOY – priority date day of year (Jan 1 = 1)

YEAR – priority date year

BEGINDOY – day of year on which the right goes into effect

ENDDOY – last day of year on which the right is in effect

REACHCOMID – for surface water rights COMID of reach from water is diverted

LENGTH\_OR\_COMID – for instream water rights, either the length of stream reach to which the right applies, or the COMID of the downstream end of the portion of the stream to which the right applies

SPECIAL – special codes used to identify how certain water rights should be handled in different scenarios (e.g. a value of 1 indicates an unconverted instream water right)

CERTIFICATE – For certificated water rights, the certificate number, or other note if the entry does not represent a certificated water right, or -99 if the data has not yet been entered.

## The wr\_pous.csv file

wr\_pous.csv is a comma-separated-values text file with the columns listed below.

POU\_INDEX – index of data record in wr\_pous.csv (0, 1, 2, …)

POU\_ID – same as for wr\_pods.csv

IDU\_ID – identifies the IDU in which the point of use is located

WRIS\_ID – “WaterRightId” in OWRD’s Water Right Information System

AREA\_POU – area of the POU, m2

PERCENT\_POU – per cent of the POU overlapped by the IDU

AREA\_IDU – area of the IDU, m2

PERCENT\_IDU – per cent of the IDU overlapped by the POU

USECODE – same as for wr\_pods.csv

PERMITCODE – same as for wr\_pods.csv

XCOORD - easting of IDU centroid

YCOORD – northing of IDU centroid

CERTIFICATE – For certificated water rights, the certificate number, or other note if the entry does not represent a certificated water right, or -99 if the data has not yet been entered.

Note that the POU\_INDEX values are sequential and unique, but POUID values are not necessarily unique, reflecting the fact that water from a single point of diversion may go to multiple points of use. Before the POU\_INDEX values are added, the file is sorted by POUID and IDU\_ID.

The POU file includes an IDU\_ID field, which is used to identify the IDU in which the point of use is located. In future, this issue could be handled by adding two columns containing the x,y coordinates (easting, northing) of the point of use to the POU file. Logic could then be added to the cold start process in OUWIN to populate the IDU\_ID column based on the location of the POU.

## Adding a water right

To add a water right to the wr\_pods.csv and wr\_pous.csv files, follow these steps.

1. Determine the highest value in the PODID field of the wr\_pods.csv file; assign the next higher value as the PODID value for the new water right.

2. If the new water right is an instream water right, set its POUID to -99. If it is for a municipal water system, set its POUID = - UGB. Otherwise, determine the highest value in the POUID field of the wr\_pous.csv file; assign POUIDs to the new water right starting with one greater than that highest value.

3. If the new water right does not correspond to an entry in the OWRD database, assign a WATERRIGHTID to it equal to the next unassigned number in the series of WATERRIGHTIDs which begin with 200000. For example, a water right corresponding to a 1945 judicial decree, which is not represented in the OWRD database, is assigned a WATERRIGHTID value of 200084 in the CW3M PODS file.

4. Add an appropriate point-of-diversion record to the end of the wr\_pods.csv file. Note that for groundwater rights, REACHCOMID and LENGTH\_OR\_COMID should be set to -99. For an instream water right, COMID should be set to the reach at the upstream end of the water right; LENGTH\_OR\_COMID should be set either to the length along the stream in feet to which the right applies or to the COMID of the reach at the downstream end of the right; the X and Y coordinates, if unknown, should be set to a point on or near the upstream reach.

5. Insert the new point-of-diversion record(s) into the wr\_pods.csv file in sorted order, or sort the entire wr\_pods.csv file by priority year and day and the portion of the year for which the right is in effect (sort by YEAR, PRIORITYDOY, BEGINDOY, ENDDOY, WATERRIGHTID, X, Y, PODID). This completes the changes to the wr\_pods.csv file. If the new water right is for a municipal water system, no changes are necessary to the wr\_pous.csv file. Otherwise, continue with the next step for additions to the wr\_pous.csv file.

6. At the end of the wr\_pous.csv file, add one record for each point of use. Sort by POUID. Recalculate the POU\_INDEX column. This completes the changes to the wr\_pous.csv file.

# Stream flow and stream temperature

## Water parcels

Water flows continuously. Digital computers use discrete quantities to represent, approximately, the continuous elements and properties of the real world. CW3M accounts for the water on a landscape as “parcels”, represented in the C++ code as objects of the class WaterParcel. The properties of a water parcel, represented in C++ as members of the WaterParcel class, are

volume, expressed in units of cubic meters

thermal energy, expressed in units of kJ, relative to 0 for liquid water at 0 deg C

The volume property is used as a surrogate for mass, at a constant density of 998.2 kg per cubic meter. This approximation reflects the fact that observational data for water is always in units of volume, and the convenient reality that the density of liquid water is relatively constant over the range of temperatures encountered in natural environments. In the future, the WaterParcel class could be extended to include other properties, such as sediment load and dissolved pollutants.

In CW3M, spatial units have water parcels associated with them. Each subreach in the stream network has a parcel of water in it, whose properties change from one daily timestep to the next. The total volume of a reach is the sum of the subreach volumes, and the total thermal energy is the sum of the subreach thermal energies. Landscape polygons (“IDUs”) and bodies of water also have associated water parcels.

## Daily water mass and energy balance

Thermal energy algorithms are being added to CW3M in 2020 as part of the McKenzie Basin Wetlands Study, described in a later chapter of this document. Inspiration and technical information for the thermal energy code is from the 204-page manual for Heat Source Model Version 7.0, prepared by Matthew Boyd and Brian Kasper in 2003 and 2007 for the Oregon Department of Environmental Quality (Boyd & Kasper 2003).

CW3M estimates the properties of water parcels at a daily timestep. The basic equation for daily subreach volume is straightforward

Vt = Vt-1 + Vup + Vlateral - Vdown - Vevap

where (all quantities in m3)

Vt = volume in day t

Vt-1 = volume in the previous day

Vup = volume flowing in from upstream

Vlateral = volume entering (+) or leaving (-) the subreach through the stream banks or streambed, or from withdrawals for irrigation or municipal use, or discharges from municipal points of central discharge

Vdown = volume flowing out to downstream

Vevap = volume lost to evaporation

The equation for subreach thermal energy has additional terms

Et = Et-1 + Eup + Elateral – Edown + ESW – ELW - Eevap

where (all quantities in kJ)

Et = thermal energy in day t

Et-1 = thermal energy in the previous day

Eup = thermal energy in the water flowing in from upstream

Elateral = thermal energy entering or leaving in water from stream banks, withdrawals for irrigation or municipal use, groundwater exchange, etc.

Edown = thermal energy leaving in water flowing out of the reach

ESW = incoming shortwave solar radiation

ELW = outgoing longwave radiation

Eevap = energy carried away from the reach through evaporation

There are corresponding equations with somewhat different terms for landscape polygons and bodies of water. The equations attempt to account for first order effects; they neglect effects which are usually (but not always) of lesser magnitude: the conversion of mechanical energy to thermal energy, convective heat exchange with the air and the streambed, and so on.

Thermal energy density (i.e. temperature) affects the rate of evaporation and the outgoing longwave radiation. As a result, the mass and energy balance calculations are interrelated;

The estimate of thermal energy is made in the same subroutine which calculates the flow in the reach, so that the flow to downstream can be corrected for the loss of water to the atmosphere by evaporation.

## Estimating the rate of flow in a stream reach

CW3M uses a kinematic wave algorithm to estimate the average daily flow rate in each subreach and reach. Each reach is represented as an ordered set of equal length subreaches. The maximum subnode length is specified in meters in the Flow XML file in the *subnode\_length* field of the <streams> block. Reaches shorter than the specified subnode length consist of a single subreach. Reaches longer than the specified subnode length are divided into subreaches of equal length, where the number of subreaches is chosen so as to make it as small as possible while keeping the subreach length less than or equal to the specified value of subnode length.

The kinematic wave algorithm is used to estimate the average daily outflow from each subreach. The daily flow rate for the reach is taken as the average daily flow rate of the most downstream subreach of the reach.

The daily outflow from a subreach is a function of the length and average slope, the amount of water in the reach, yesterday’s outflow, today’s inflow from upstream, and today’s inflow from the seepage into the stream from the banks of the stream (a.k.a. lateral flow). The subreach slope, the parameters *n* and *wd\_ratio*, and yesterday’s outflow are used to calculate the width and depth of the channel, with the assumption that the channel is rectangular and that its width-to-depth ratio is parameterized, with a default value of 10. *wd\_ratio* is an optional field in the <streams> block of the Flow XML file.

The kinematic wave algorithm itself is parameterized with a value for *n* = 0.3. As implemented, the algorithm makes the rate of flow out of a subreach more immediately responsive to the inflow from upstream than to the lateral flow. In the original WW2100 implementation, this characteristic led to unrealistic accumulation of water in headwater reaches, since by definition there is no inflow from upstream into the upstream end of a headwater reach. A workaround was later adopted to compensate for this malfunction, in the form of logic which treats any volume in a subreach in excess of the sum of the current day’s actual inflow from upstream and the current day’s lateral flow as if it were part of the current day’s inflow from upstream.

## Water temperature from thermal energy

The amount of thermal energy in the water in a reach or reservoir, referenced to zero energy for liquid water at the freezing point of water, is estimated and tracked within CW3M’s Flow model. The average temperature of the water in a reach can then be calculated for output purposes from the thermal energy per unit volume

temperature = thermal energy / (volume \*water density \* specific heat of water)

where

temperature = average temperature of the water in the reach (degC)

thermal energy = the thermal energy of the water in the reach, rel to the freezing pt. (KJ)

volume = volume of water (m3)

water density = 998.2 kg/m3

specific heat of water = 4.187 kJ/(kg degC)

## Initial conditions for Flow: the IC file

The Flow model has the ability to read initial values for the water in the stream network from an IC file. The name and location of the IC file are specified in the initial\_conditions field of the <flow\_model> block of the Flow XML file. The Flow XML file itself is specified in the ENVX file. When the IC file is not specified or cannot be accessed, Flow initializes with nominal water amounts and flows; customarily, a 10-year simulation from that point is used for spinup. On completion of every simulation run, CW3M saves a new IC file with the values from the end of the run, to the user’s Documents folder. The name of the newly saved file is suffixed with “.ic<year>” (e.g. “.ic2006”), where “year” is the calendar year following the final year of the simulation run.

## Boundary conditions for stream water temperature

Water enters stream reaches from upstream and from lateral flow. As of 9/10/20, two symbols are used in the source code to parameterize the temperature of water entering the streams:

#define DEFAULT\_SOIL\_H2O\_TEMP\_DEGC 5.

#define DEFAULT\_REACH\_H2O\_TEMP\_DEGC 10.

The soil temperature parameter value is used for water entering through the stream banks in the HBV submodel. The reach water temperature is used when initializing flow data in the absence of an IC file.

Further elaboration of water temperature boundary conditions is necessary. Water returns to stream reaches from municipal water systems at points of central discharge. Municipal discharge water is typically warmer than stream water, and its temperature may vary seasonally. The temperature of the water reaching the streams via the stream banks also varies seasonally (e.g. cold streams in spring from snow melt). A 2019 article by Leach and Moore in Water Resources Research provides some clues and further references for improving the representation of the temperature of water entering via the stream banks.

## Thermal stratification in reservoirs

Initially, for the purpose of simulating water temperature, reservoirs will be represented as extremely large stream reaches characterized by a single uniform temperature. Discharges wil be at that temperature. This is an unfortunate oversimplification, because in reality temperature is a function of depth during the summer, and the Army Corps of Engineers can manage downstream water temperatures to some extant by choosing how much water to release from outlets at different depths.

The initial oversimplification is necessary due to the lack of adequate (and adequately simple) algorithms for simulating thermal stratification and for simulating USACE’s daily operating decisions about how much water to release from different available outlets.

## Thermal loading

A thermal loading algorithm will be implemented in CW3M as part of the McKenzie Basin Wetlands Study. The scope for the study calls for replication in CW3M, to the extent that it is practical, of the methods used in the Shade-a-lator model, part of the Heat Source model. Heat Source and Shade-a-lator are maintained by the Oregon Department of Environmental Quality.

For CW3M, the relevant output of Shade-a-lator is the thermal load in kcal/day of insolation on specific stream segments. Shade-a-lator calculates the kcal/day figure for each “node” along a stream; nodes are typically 25 meters apart. A single node is characterized by elevation, aspect, stream width, right and left bank vegetation height and density, and topographic shading.

CW3M divides streams up into reaches from the National Hydrography Dataset, and subdivides the reaches into subreaches. Within a reach, subreaches are of equal length and no longer than 1000 meters. Reaches are represented by a series of points; conceptually, the stream flows from point to point. Importantly, the points are not equally spaced and are not collinear. Some reaches are curved, and are represented by relatively many closely-spaced points. Other reaches are straighter, and are represented by fewer points spaced farther apart.

CW3M represents the McKenzie system with 1,047 reaches of average length 1,781 meters. The longest reach is 9,010 meters; the shortest is just 6 meters. The Reach\_McKenzie.shp file which stores the points which define the reaches is 6,361,228 bytes long, an average of 6,076 bytes per reach. Even if each point required as many as 100 bytes of storage, that would be an average of 61 points per reach and a total of 63 thousand points, representing more than 60 thousand straight stream segments averaging about 30 meters in length. Double precision floating point numbers require 8 bytes of storage, so 3 coordinates, if stored as double precision floating point numbers, would require only 24 bytes. So it is likely that each point takes up much less than 100 bytes, and that hence there are many more than 63 thousand points altogether, with an average distance between them of much less than 30 meters.

Short, straight stream segments correspond to the nodes used in Shade-a-lator, as they can be characterized by single values for elevation, aspect, stream width, and vegetation characteristics. Elevation and aspect can be calculated from the 3D coordinates of the points themselves. Other values, e.g. vegetation characteristics, are available from the IDUs within which the stream segments are situated. Since there are only 16,883 IDUs, the values derived from the IDUs would necessarily apply, on average, to about 4 contiguous stream segments. On sharply curved reaches with closely spaced points, the same IDU-derived values would apply to many such contiguous segments.

Since the aim is to reproduce the Shade-a-lator results as much as is practical, we propose to create an additional GIS data layer, similar to the reach layer but more detailed spatially. Since the terms “subreach” and “subnode” have already been used in the CW3M code base to refer to the equal length pieces of each reach used in the flow calculations, we’ll call this new layer the “stream segment” layer. Its characteristics are:

* segments are subdivisions of reaches
* segments are straight and defined by just 2 points, the endpoints, which are themselves points from the reach of which the segment is a part
* segments are not less than 25 meters in length, except when the reach itself is less than 25 m long
* segment attributes include midpoint elevation, aspect, slope, and topographic shading, all derived from the reach file and digital elevation map
* each of the two stream banks for each segment is associated with an IDU, which may be the same IDU for both banks; since segments may cross more than one IDU, a rule will have to be devised to pick the IDU most characteristic of the stream bank, when there is more than one
* additional segment attributes are derived from the IDUs which the segment traverses, and include vegetation type, height, and density or some other characterization of vegetative shading
* additional attributes may be necessary to satisfy the data requirements of the Shade-a-lator algorithms (e.g. to calculate bank shading), for example channel width under base flow conditions

The stream segment layer would thus consist of simple straight line segment, generally at least 25 meters in length, defined by points already present in the reach layer. Reaches would decompose into one or more continuous segments. Segments would be in a many-to-one relationship with reaches. Segments would be the unit of computation for the Shade-a-lator—like thermal loading calculations.

Some of the data needed for the thermal loading calculations will be constant and can be precalculated offline, for example topographic shading characteristics. Other data may change seasonally (vegetation density) or interannually (tree height). Insolation is also dependent on the season and the weather. Accordingly, the thermal loading calculation will be added to the daily calculation of stream flow for each reach

# Creating a new study area from a watershed within the WRB

Any complete watershed, whether the entire Willamette River basin, a tributary subbasin such as that of the North Santiam River, or a smaller drainage like the Chicken Creek watershed, may be used as a study area. Moreover, a study area may be formed from the combination of several named tributary basins, so long as they combine to a single pour point. For example, the upper Willamette basin study area incorporates the areas drained by the Coast and Middle Forks of the Willamette River together with the McKenzie River watershed.

The spatial extent of the study area is defined by the IDU shapefile. Reach and HRU shapefiles are also required, and must be consistent with the IDU shapefile. Once a particular drainage has been selected as a study area, the necessary shapefiles are made from the larger WRB shapefiles using ArcMap.

Tools/Analysis/Extract/Select is used to produce the IDU file for the target area from the WRB IDU file. Selections may be made on the SUB\_AREA attribute or the HBVCALIB attribute. The query expression must be chosen so as to produce a whole watershed. The SUB\_AREA attribute generally identifies the areas drained by the major tributaries of the Willamette River. Each single value of SUB\_AREA from 1 through 11 selects a whole watershed:

|  |  |  |
| --- | --- | --- |
| SUB\_AREA | Tributary | COMID of outlet reach |
| 1 | McKenzie | 23765583 |
| 2 | Molalla and Pudding | 23800560 |
| 3 | Clackamas | 23809000 |
| 4 | Long Tom | 23763071 |
| 5 | Marys | 23762881 |
| 6 | North Santiam | 23780877 |
| 7 | South Santiam | 23785607 |
| 8 | Tualatin | 23792815 |
| 9 | Coast Fork | 23759222 |
| 10 | Middle Fork | 23751752 |
| 11 | Upper Yamhill above McMinville | 23791899? |
| 12 | Upper Willamette mainstem | 23763395 |
| 13 | Lower Santiam | 23780405 |

Selections of whole watersheds may also be made using the HBVCALIB attribute, but unlike SUB\_AREA, several values of HBVCALIB may be necessary to select for a complete drainage because some HBVCALIB drainages are nested within others. For example, the ones for the Cougar and Blue River reservoirs are nested within the one for the McKenzie above Walterville. In such cases, the selection should be made on all the HBVCALIB values, e.g. HBVCALIB = 34 OR HBVCALIB = 8 OR HBVCALIB = 9 would select for the portion of the McKenzie basin which drains to the gage at Walterville. The HBVCALIB tab in CW3Mhandbook.xlsx lists the HBVCALIB drainages, and Figure 1 illustrates many of their locations within the WRB.

A third attribute, Sub\_Area\_C (“calibration subareas”), identifies 19 small watersheds which were originally identifed for use in an early WW2100 HBV calibration. They are listed on the Sub\_Area\_C tab of CW3Mhandbook.xlsx.

To prepare the necessary subbasin shapefiles, the ArcMap Selection and Clip tools are used (in ArcMap, Tools/Analysis/Extract/Select and …/Clip).

The Select tool is used to create the subbasin Reach and IDU layers from the WRB Reach and IDU layers. The selection is usually made on the HBVCALIB attribute. For example, HBVCALIB = 9 would select the Blue River reservoir drainage. Note that some HBVCALIB drainages are nested within others, e.g. the ones for the Cougar and Blue River reservoirs are nested within the one for the McKenzie above Walterville. In such cases, the selection should be made on all the HBVCALIB values, e.g. HBVCALIB = 34 OR HBVCALIB = 8 OR HBVCALIB = 9 would select for the portion of the McKenzie basin which drains to the gage at Walterville. For the North Santiam basin, the expression would be HBVCALIB=12 OR HBVCALIB=37 OR HBVCALIB = 44.

Selections may be made on other attributes, but the “whole watershed model” concept requires that the selected area should form a watershed draining to a single point. Single values of the SUB\_AREA attribute select for major subbasins (e.g. SUB\_AREA = 3 selects for the Clackamas River drainage). Single values of the Sub\_Area\_C attribute select for smaller watersheds used in the original HBV calibration work.

The Clip tool is used to clip the WRB HRU layer to the extent of the newly created subbasin IDU layer, to create the subbasin HRU layer.

Subbasins which are not currently defined by any value of SUB\_AREA or Sub\_Area\_C or any combination of HBVCALIB values may be defined by adding to the HBVcalibPt array in WaterRights.cpp, and then running a model coldstart. The HBVcalibPt entry specifies the location or COMID of a pour point; the coldstart logic sets the HBVCALIB attribute to the specified value for all the reaches and IDUs which drain to that pour point, and which have not already been assigned an HBVCALIB value. To activate coldstart, set the coldstart parameter to 1 in the settings block of the .envx file. Since the coldstart function generates indices which are preserved in subbasins, it should only be used when simulating the complete Willamette River basin study area.

The newly created subbasin shapefiles should be placed in a folder in the DataCW3M directory; that folder should be named for the target subbasin. For example, the shapefiles for the North Santiam watershed are in DataCW3M\NSantiam. Any other files specific to the subbasin should also be placed in the subbasin folder, except for the subbasin ENVX file itself. By convention, the name of the subbasin ENVX file is composed as <model name>\_<subbasin name>.envx. For example, the ENVX file for the North Santiam subbasin is named “CW3M\_NSantiam.envx”. ENVX files should be placed in the DataCW3M directory.

Here is an example of the names and locations of all the files specific to a particular subbasin.

DataCW3M (folder)

CW3M\_McKenzie.envx

McKenzie (folder)

Flow\_McKenzie.xml

HRU\_McKenzie shapefile

IDU\_McKenzie shapefile

Reach\_McKenzie shapefile

# North Santiam study area

The North Santiam (NSantiam) study area (Figure 3) consists of the watershed of the North Santiam River down to the point where the North and South Santiam Rivers come together to form the Santiam River itself. The outlet reach of the study area has COMID 23780877. Its area is 469,061 acres; it is comprised of 11,001 IDUs, 686 HRUs, and 710 reaches. Various parameter values for the NSantiam are recorded in the “NSantiam” tab of the NSantiam.xlsx file in the CW3Mhandbook folder. In addition, there is a separate file devoted to data for the North Santiam study area, called “NSantiam.xlsx”. There are tabs in NSantiam.xlsx labeled

Municipal Populations

Municipal Water

Muni WR details

Instream Water Rights

existing instream WR details

unconverted WR details

Water Right Codes

## Instream water rights

Per Joel Plahn at OWRD on 12/13/18, there are 6 instream water rights and 3 unconverted applications for instream water rights in the North Santiam basin. All are owned by OWRD. There is also a judicial decree from 1945. In the list below, the number in the leftmost column is the water right ID for those currently included in CW3M. Prescribed minimum flow rates are stated in cubic feet per second. Some prescribed instream water right minimum flow rates vary seasonally; where that is the case, the smallest and largest flow rates are given.

North Santiam R.

- 1945 decree from Gardner Bennett diversion to the mouth 50.0 cfs

200081 appl# MF141 at USGS gage 14-1841 near Jefferson at Greens Bridge 6/22/64 430.0 cfs

reach 23780833; one order 3 reach

200082 appl# MF142 at USGS gage 14-1830 at Mehama 6/22/64 580.0 cfs

reach 23780481; one order 5 reach

200083 appl# MF143 at USGS gage 14-1815 at Niagara 6/22/64 500.0 cfs

reach 23780511; one order 5 reach

118093 cert# 65756 at USGS gage 14-1780 near Detroit 6/22/64 345.0 cfs

reach 23780591; one order 4 reach

Little North Santiam R.

118092 cert# 65755 Little North Santiam R. at USGS gage 14-1825 near Mehama 6/22/64 40.0 cfs

reach 23780805; one order 3 reach

124853 cert# 72598 Little North Santiam R. from Battle Ax Cr. to the mouth 10/18/90 40.0-180.0 cfs

reaches 12780851, …0853, …0855, …0857, …0859, …0861, …0863, …0865, …0867, …0869,

…0871, …0873; one order 2 reach and 11 order 3 reaches

Creeks

124850 cert# 72595 Stout Creek from Shellburg Creek to the mouth 10/18/90 1.75-20.0 cfs

reach 23780991; a headwater (order 1) reach

124851 cert# 72596 Rock Cr. from East Fork Cr. to the mouth 10/18/90 3.0-50.0 cfs

reaches 23781441, …1453, …1473, …1485; three order 2 reaches and one order 3 reach

124852 cert# 72597 Mad Cr. from the headwaters to the mouth 10/18/90 2.0-22.0 cfs

reach 23781465; a headwater reach

Previously there had been a different unconverted right at the mouth of the N. Santiam:

1930 at the mouth of the N. Santiam R. 1000-1500 cfs

reaches 23780877, …0879, …0881, …0883; 4 order 5 reaches



Figure 6. Instream water rights in the North Santiam watershed

## Municipal water rights

The W3CM water rights data includes actual municipal water rights for withdrawals from the North Santiam River for 5 urban growth areas (Salem-Keizer, Stayton, Lyons, Gates, and Detroit). Details of these water rights are in the “Muni WR details” tab of the NSantiam.xls file. Maximum diversion rates vary from 62 cfs for Salem down to 1.7 cfs for Gates. Normalized by average 2010-17 simulated population, the maximum diversion rates vary from 164 gal/day/person for Salem-Keizer (pop. 244,141) up to 6,853 gal/day/person for Detroit (pop. 212) (see the “Municipal Water” tab of NSantiam.xlsx).

# McKenzie Basin Wetlands Study

## Project Overview

The EPA has funded the Lane Council of Governments (LCOG) to carry out a study which includes use of CW3M to simulate the McKenzie River basin (Figure 7). The purpose of using CW3M in this study is to simulate changes in the extent of McKenzie basin wetlands and changes in their nature, over the next five decades as climate changes. One effect of wetlands which is of particular interest is on the temperature of water returning to the stream network from the downstream end of the wetlands. As of the beginning of the project, CW3M does not have a functional stream temperature model. The project scope includes re-implementing in CW3M some of the Heat Source/Shade-a-lator model (Boyd & Kasper 2003) used by the Oregon Water Resources Department, to provide simulations of daily stream temperatures along with daily flows.

Some earlier sections in this document (“Daily water mass and energy balance” and “Water temperature from thermal energy”) describe a stream temperature submodel based on Boyd & Kasper 2003. Those sections were written a year before the EPA funding came through. The submodel that they describe was not implemented at that time. Those sections will be further developed and used as the specification for the stream temperature submodel in the McKenzie wetlands study.

LCOG has subcontracted the work to Land Craft, LLC, which is operated by David Richey. Oregon Freshwater is a subcontractor to Land Craft. David Conklin will do most of the work for Freshwater. The Freshwater-Land Craft contract stipulates that the additions and refinements to CW3M which Freshwater develops for this study will be placed in the public domain as part of CW3M. Kyla Zaret, a wetland ecologist at the Institute for Natural Resources, is providing expertise about wetlands to the project. The McKenzie wetlands study started in late June 2020 and is expected to be completed by the end of 2021.

Kyla’s 1/23/20 report on another project (Zaret 2020) lists six types of wetlands benefits: flood attenuation, late season flow provision, habitat for at-risk species, temperature, nitrogen and phosphorus reduction, and groundwater recharge. The LCOG McKenzie Wetlands project will certainly address temperature, and may perhaps make use of the model of flood attenuation that Kyla describes in her report. What other wetlands benefits are addressed remains to be determined as the project begins.

![A screenshot of a map

Description automatically generated]()

Figure 7. McKenzie basin in CW3M screen capture

![A close up of a map

Description automatically generated]()

Figure 8. Wetlands in the lower McKenzie basin, with their WETL\_ID attribute values

## Model and Simulation Overview

2010-18 will be used as a calibration period. Future simulations will be made for 2019-2060. If actual data for 2019 is available, we may choose to extend the calibration period through 2019 and begin future simulations in 2020.

CW3M’s IDU layer for the McKenzie basin currently has 16,883 polygons with a total area of 330,708 hectares. Its reach layer has 1047 reaches. There are 954 HRUs, representing contiguous smaller areas which drain to a single reach or to several adjacent contiguous reaches. HRUs are made up of IDUs; HRU boundaries are coincident with IDU boundaries.

Water comes into reaches three ways: 1) from upstream reaches, 2) as lateral flow from streambanks, or 3) from sources identified explicitly in the Flow XML file (e.g. high Cascades groundwater). Every reach is associated with a single HRU (Reach layer attribute HRU\_ID). Some or all of the drainage from the associated HRU flows into the reach. The water draining from a single HRU may be divided up among several reaches. Reach layer attribute HRU\_FRAC specifies how much of the drainage from the HRU associated with the reach goes into the reach.

The amount of wall clock time that it takes to execute CW3M is roughly proportional to the numbers of IDUs and reaches in the study area. At the current sizes, simulation of the McKenzie basin for 2010-60 takes about four and a half hours on a moderately fast desktop PC.

We anticipate that new, more detailed IDU, reach, and HRU layers will be constructed during the course of the project. If the new reach layer were based on the most detailed version of the National Hydrography Dataset (NHD), it would contain about 13,000 reaches. We expect to identify hundreds to thousands of wetlands in the McKenzie basin. We think the new IDU layer will have less than 100,000 polygons. For comparison, the WW2100 IDU layer had 180,000 polygons, and each full length simulation of a single WW2100 scenario took several days to execute.

CW3M has a 3-layer land use/land cover (LULC) hierarchy. The top level has just 8 categories (Unknown/Developed/Agriculture/Other veg./Forest/Barren/Wetlands/Water snow ice). As of 7/2/20, the top and middle levels in the hierarchy each have only a single Wetlands category (LULC\_A = 6 and LULC\_B = 61), and the bottom level has just two, Woody Wetlands (VEGCLASS = 190) and Herbaceous Wetlands (VEGCLASS = 195). Sixty-five IDUs totaling 519 hectares are classified as wetlands. All but four of the wetland IDUs are classified as woody wetlands; those total 500 hectares. The other four IDUs, classified as herbaceous wetlands, are near the point where the McKenzie flows into the Willamette.

We expect to add many more (a few dozen?) wetland categories to the bottom level of the LULC hierarchy (Cowardin categories?; Cowardin & Golet 1995) and possibly some to the middle level as well (flood plain wetlands, upland rain-fed wetlands?).

## McKenzie wetlands in the initial versions of the IDU, HRU, and Reach data layers

There is an Excel spreadsheet named “Wetlands.xslx” in the CW3M Digital Handbook folder. It has data for wetlands in both the McKenzie and Clackamas basins. Initial data for the McKenzie shows 18 wetlands (WETL\_ID 1 through 18; Figure 8) ranging in size from 7 to 162 ha and totaling 519 ha. For comparison, Clackamas data has 12 wetlands (WETL\_ID 19 through 30), ranging in size from 5 to 38 ha and totaling 204 ha.

## Data changes for better representation of wetlands

Note that CW3M has a convention that the LULC attributes of an IDU may change only from one year to the next, not multiple times within a single year.

1. Use the LULC\_A and LULC\_B attributes of wetland IDUs to represent things that rarely if ever change, such as landscape position and soils.  Use the third level LULC attribute (VEGCLASS) to represent vegetation classifications, for example to differentiate a cattail pond from a swamp with woody vegetation.  Use other attributes to represent things which change seasonally or daily, for example a WETNESS attribute for inundation depth and soil moisture.

2. Develop a shapefile which represents historic, current, and potential future wetlands, divided into polygons by LULC\_B values.  Intersect that shapefile with the existing IDU shapefile to produce a new IDU shapefile with more IDUs, where the boundaries of the IDUs in the original IDU shapefile are coincident with the outer boundaries of contiguous sets of 1 or more IDUs in the new IDU shapefile.

3. Populate initial condition data attributes in the new IDU layer with data for those attributes in the original IDU layer, except assign LULC\_A, LULC\_B, and VEGCLASS attribute values for wetland IDUs using the new classes developed in the first step.

## Projection, Calendar, and Units

CW3M’s spatial data files use the NAD\_1983\_UTM\_Zone\_10N projected coordinate system.

Some daily climate datasets include leapdays and some don’t. CW3M accomodates both, but the demo climate dataset included in the CW3M\_Installer\_...exe files does not include leapdays. As a consequence, reports which compare daily simulated values with daily observed values generate a warning about inconsistent calendars when the Demo scenario is simulated.

CW3M can aggregate results from daily to yearly on either a calendar year basis or a water year basis. For this study, a water year basis seems more appropriate. Climate datasets begin on January 1st and end on December 31st. Simulations also begin on January 1st and end on December 31st, regardless of whether the simulation results are aggregated on a calendar basis or water year basis. This has the consequence that when a 51-year simulation run is carried out, water year results are presented for only 50 complete water years, starting with October of the first calendar year and ending with September of the final calendar year. For example, when CW3M is run for the 51 (calendar) years 2010-2060, it produces results for only 50 complete water years, 2011-2060. Water years are named by the calendar year in which they end.

native units are metric. In the CW3M output files, areas will be presented in hectares, depths in meters, volumes in cubic meters, flows in cubic meters per second (cms), temperatures in Celsius, and precipitation in millimeters of water.

## Simulation of changes in wetlands over time

CW3M will be used in this study to address the question of how McKenzie basin wetlands might change over the next half-century. In order to produce results which are relevant, the model must be able to produce changes in the wetlands in response to other changes, both natural and anthropogenic. Natural changes as used here are changes to the precipitation regime, seasonal temperatures, and so on. Anthropogenic changes would include development encroaching on wetland, changes in the upstream flow regime due to changes in reservoir operations or irrigation withdrawals, and so on. As of the beginning of the study, CW3M treats IDU wetlands as static: once a wetland, always a wetland. Development in wetlands is not represented in CW3M’s land use model, nor is the loss of wetlands due to drainage, drought, or conversion to agriculture. At the very least, we will need to implement logic to tie the areal extent of a wetland to the quantity of water available to nourish it, as precipitation and from upstream. And we will need new logic to tie the temperature and volume of the water flowing out to the temperature and volume of the water flowing in.

## How wetlands are represented in the model

In CW3M, the areas and shapes of IDUs are fixed in the model’s initial data and do not change during the simulation. This has the consequence that, in a given simulation year, an IDU may be classified (the LULC\_A attribute) as a wetland in its entirety or as not-a-wetland (e.g. agricultural or forested) in its entirety, but not as a combination of wetland and not-a-wetland. From one simulation year to the next, the classification of an IDU can be changed, for example from wetland to agricultural or vice versa. As noted previously, as of the beginning of this project, in CW3M wetlands are static; there is no logic to change an IDU’s LULC\_A attribute from wetland (LULC\_A=6) to anything else, nor any logic to change from something else to the wetland value. New logic to do so is discussed later in the section titled “Loss (or gain) of wetlands”.

The condition of a real wetland changes both seasonally and interannually. We’ll add a WETNESS attribute to represent how wet a wetland IDU is on a given day. The value of the WETNESS attribute will be set in the daily simulation loop. The WETNESS attribute is discussed below in the section titled “A WETNESS attribute”.

The representation of a wetland IDU most consistent with the overall CW3M design is as a flat-bottomed pool with soil at the bottom and vertical sides of uniform height. The vegetation type and water depth are taken as uniform across the area of the IDU. This representation can support outputs for water temperature and water depth whenever the wetland is inundated, and the degree to which the soil is saturated when it is not inundated. A more elaborate representation of a wetland IDU would be as a bowl with a curved bottom, so that increasing fractions of the IDU’s area are inundated as the water level rises, but we won’t attempt that representation in this project.

Conceptually, each wetland IDU adjacent to a reach may be visualized as a pool adjacent to a channel. When the wetland is wet and flow in the channel is low, water moves out of the pool into the channel by overflowing the side of the pool, and it can also move through the soil to the channel. When the wetland is dry and flow in the channel is higher, water can move from the channel into the pool, over the banks of the channel. CW3M does not have a mechanism for moving water laterally out of the channel directly into the soil of the adjacent IDU.

The pool has a capacity (idu WETL\_CAP, in units of depth). In this simple wetland model, we parameterize the reach with two values, a threshold flow (reach Q\_CAP, in cms), and a fraction (reach QSPILL\_FRC). Water always flows longitudinally down the channel, but it can flow rates above Q\_CAP, the portion of the flow above Q\_CAP is divided between flow down channel and flow laterally over the sides of the channel into the adjacent pool.

A wetland IDU separated from a stream by another wetland IDU may be visualized as a second pool adjacent to the first but on the other side from the channel. The rim of the second pool is at the same height as the first pool, but the bottom of the second pool may be higher than the bottom of the first pool, so that the capacity per unit area of the second pool is smaller than the capacity per unit area of the first pool. The two pools are connected at the level of the bottom of the second pool, so the water level is the same in the two pools, as long as it is high enough in the first pool to reach the level of the bottom of the second pool.

The conceptualization described so far allows for nourishment of the wetland idus from a nearby reach, but it does not account for lateral flow into the wetlands from the soil of adjacent non-wetland IDUs. Nor does it account directly for a wetland slowing the runoff from upland precipitation. CW3M uses a version of the HBV precipitation-runoff model. HBV, at least as in CW3M, represents only lateral flow from the land into the stream, not from one parcel of land to an adjacent parcel. Even with these omissions, the conceptualization described so far may result in reducing the hydrograph peaks, since some of the water will detour into the adjacent pools on its way downstream.

Elaboration of CW3M’s precipitation-runoff submodel to include a representation of lateral runoff or subsurface flow between adjacent IDUs would entail changing the principal unit of computation from HRUs to the IDUs of which the HRUS are composed. This would amount to a major extension (or replacement) of the HBV submodel, and is outside the scope of the current project.

Another consequence of the current conceptualization is the inability to represent wetlands which are not adjacent to a reach. A single real wetland may be represented by multiple wetland IDUs forming a contiguous area, so long as at least one IDU is adjacent to a reach. Wetland #18, consisting of a single IDU (IDU\_ID=149851) in an HRU (HRU\_ID=2344) which drains to a reach of McGowan Creek (COMID=23773619), is an example of a wetland IDU not adjacent to a reach nor connected by adjacency to other wetland IDUs.

## Attributes of interest in the wetlands study

A number of attributes of the IDU, HRU, and Reach data layers may be used as inputs and outputs in the wetland simulations. An initial set of such attributes is:

WETL\_ID, WETNESS, WETL\_CAP in the IDU layer (new)

Q\_CAP, QSPILL\_FRC in the reach layer (new)

Q in the Reach layer, the flow in the outlet reach of the wetland

REACH\_H2O in the Reach layer, the volume of water in the reach

TEMP\_H2O in the Reach layer (new), reach water temperature

PRECIP in the IDU and HRU layers, precipitation

TEMP in the IDU and HRU layers, air temperature

AWS, SM\_DAY, and SOILH2OEST in the IDU layer, discussed below

## A WETNESS attribute

A new IDU attribute, WETNESS, is proposed as a generalization of the attributes for soil moisture. The calculation of WETNESS would likely make use of existing attributes for soil water holding capacity (AWS) and soil moisture (SM\_DAY and/or SOILH2OEST). Positive values of WETNESS are simply average water depth when the surface is covered by water. A value of zero indicates fully saturated soil with no standing water. The magnitude of negative values of WETNESS indicates how much water would have to be added to the soil to fully saturate it.

The idea of a WETNESS attribute was suggested by the use of negative “water depths” by Poiani and Johnson in their prairie wetland model (Poiani & Johnson 1993). Here is their description:

…negative “water depths” were calculated for certain cells in the GIS. This approximated depth to groundwater for vegetation types that were not permanently flooded or saturated. For example, suppose the water elevation over the entire wetland basin was 557.7 metres above sea level (m.a.s.l.). A cell in the center of the basin with a ground elevation of 557.0 m.a.s.l. would have a water depth of 0.7 m. In contrast, a cell at the edge of the wetland with an elevation of 558.0 m.a.s.l. would have a “water depth” (or depth to groundwater) of -0.3 m.

The proposed WETNESS attribute is the same as water depth for positive values, but differs from Poiani’s negative water depth in value. Poiani’s negative water depth is referenced to the elevation of groundwater, which is presumably the elevation of the water level in the nearest portion of their study area that has standing water. Negative values of the WETNESS attribute would instead be calculated from soil water holding capacity and an estimate of current soil moisture, probably using existing IDU attributes AWS, SM\_DAY, and SOILH2OEST.

Existing IDU attribute AWS is described in the CW3M data dictionary as “average soil water holding capacity” from SSURGO, in units of cmH2O. We can adjust the AWS values for wetland IDUs to tune our wetland model.

Existing IDU attribute SM\_DAY is the amount of water held in the soil, in mm, as tracked by the CW3M’s precipitation/infiltration/runoff submodel. It can change daily. Conceptually it applies to the soil from the surface down to a point too deep to be accessible by plants and too deep for water to flow laterally into the nearest downhill stream reach. SM\_DAY does not include aquifer water.

Existing IDU attribute SOILH2OEST is an estimate of plant available soil moisture, in mm of water, calculated during the growing season separately for the irrigated and unirrigated parts of HRUs containing agricultural IDUs.

The proposed WETNESS attribute is a floating point variable with meaningful values in the range of about +3000 to -1000, with 0 indicating mud, i.e. fully saturated soil with no standing water and little oxygen. Positive values of WETNESS represent the average depth of water covering the soil, in mm. Negative values of WETNESS in principle could be derived from the SM\_DAY attribute and the soil water holding capacity (AWS):

when there is no standing water, WETNESS = SM\_DAY - AWS

This formulation allows interpretation of the magnitude of negative WETNESS values as a measure of how much more water the soil will absorb before water begins to accumulate on the surface.

## Calculating the exchange of water between the wetland and the reach

### Wetland IDU parameters

WETNESS – a variable representing how wet the wetland (mmH2O)

WETL\_CAP – a parameter representing the depth of water (mmH2O) at which the water overflows back to the associated reach, assuming Q < Q\_CAP

WETL2Q – a variable representing the overflow from the wetland back to the reach

### Reach parameters

Q – flow, cms

Q\_CAP – below this flow rate, all the water exits downstream; above this rate, a fraction spills into the adjacent wetland (cms)

QSPILL\_FRC – the fraction of Q above Q\_CAP which spills into the adjacent wetland

Q2WETL – a variable representing the flow over the banks of the reach into the wetland

When Q > Q\_CAP and WETNESS < WETL\_CAP, then

WETL2Q = 0 and

Q2WETL = (Q – Q\_CAP) \* QSPILL\_FRC

When both Q > Q\_CAP and WETNESS>WETL\_CAP, a flood condition exists. How to set the values of Q2WETL and WETL2Q remains to be specified as of 8/14/20.

When Q < Q\_CAP and WETNESS > WETL\_CAP, then WETL2Q is > 0 and Q2WETL = 0.

WETL2Q is chosen so as to keep Q <= Q\_CAP

When WETNESS >= 0, SOILH2OEST = AWS\*10 (AWS is in cm, SOILH2OEST is in mm)

When WETNESS < 0, SOILH2OEST = AWS\*10 + WETNESS

It will be necessary to add logic to HBV::HBVdailyProcess() to use SOILH2OEST for wetland IDUs when calculating the flow through the soil from the wetland into the reach. We will make the assumption that flow in the other direction, through the soil from the reach to the wetland soil, is negligible. In effect, the wetland gets its water only from precipitation and from overflow of the banks of the reach, and it loses water through overflow back to the reach and from flow through the soil back to the reach as calculated in the HBV submodel.

## Loss (or gain) of wetlands

In the real world, a wetland which dries up and remains dry for a decade or so can transition to a dryland vegetation type. Wetlands may also be lost through conversion to agricultural use or developed use. Less frequently, wetlands are sometimes restored; the wetland at the junction of Chicken Creek with the Tualatin River is an example. We will need to add a process which runs at an annual timestep to implement land use changes involving IDUs changing into or out of wetland land cover (LULC\_A changing from 6 to something else, or changing from something else back to 6).

## Reality check

We need a way to assess our model’s skill at simulating the real world. We rely on hindcasting – driving the model with actual weather data and other historical records – and comparing the simulation results with temporally correlated historical observations. A working assumption for our wetland model development is that we will have historical data available for some wetlands, such as water depth as it varies seasonally and interannually, that we can compare to our simulation results. As of 8/13/20, this data has not yet been acquired.

Per Kyla Zaret on 7/17/20:

Regarding historic data:  There's a real dearth of quantitative information pertaining to palustrine wetlands in Oregon (especially those that don't include an open waterbody like a pond, lake or reservoir).  The [National Wetland Condition Assessment](https://www.epa.gov/national-aquatic-resource-surveys/what-national-wetland-condition-assessment) (NWCA) is one program (via the EPA) through which data on water depth, etc. are collected at such sites, but there are very few sites sampled per state relative to the total number of wetlands…  I would expect DEQ and the USGS to be the owners of data pertaining to water flow, temperature and quality (at least of riverine systems).  Around Portland, I'm told that some of the special stormwater districts may collect data at palustrine systems if they own or manage properties containing those types of wetlands.  Could EWEB have such data?

## Clackamas wetlands v. McKenzie wetlands

At least in the initial phase of the study, simulations of the Clackamas basin (Figure 9) and its wetlands will be run in addition to those of the McKenzie basin, for comparison and calibration purposes. The Clackamas basin study area and simulations are described in a separate chapter of this document.

![A screenshot of a map

Description automatically generated]()

Figure 9. Clackamas basin in CW3M screen capture

# The Clackamas Basin

Data files for the Clackamas basin have been set up to allow its use as a separate study area (Figure 9). Simulations of the Clackamas basin are being run as part of the McKenzie Basin Wetlands Study, for comparative purposes. The Wetlands.xslx spreadsheet, part of the CW3M Digital Handbook, identifies 12 wetlands in the Clackamas basin, in the 0.3.3 release of CW3M.

# Directory structure and file names

The directory structure of the CW3M Subversion repository follows the pattern of many Subversion repositories:

CW3M

branches

tags

trunk

Within the trunk folder, CW3M has 4 subdirectories (a.k.a. folders):

trunk

DataCW3M

GDAL

Installer

SourceCode

The DataCW3M folder in turn has both subdirectories and data files of various kinds:

<study area> folders, e.g. NSantiam, McKenzie, Marys, …

CW3MdigitalHandbook folder

Documents folder

GriddedRecentWeather folder

MonthlyDataOnPRISMgrid folder

Observations folder

RegressionTesting folder

Reservoirs folder

<CSV data files> common to all the study areas

<XML files> common to all the study areas

CW3M\_<study area>.envx files for each study area

Individual study area folders hold folders and files specific to a single study area. For example, here is what is in the NSantiam study area folder:

Observations folder

Outputs folder (not part of the repository, but present on disk)

Flow\_2010.ic initial conditions file

Flow\_NSantiam.xml file

IDU\_NSantiam.shp and associated files for the IDU layer

HRU\_NSantiam.shp and associated files for the HRU layer

Reach\_NSantiam.shp and associated files for the Reach layer

# Release Log

CW3M\_ChickenCreekInstaller\_0.1.0.exe 12/6/18 82 MB from CW3M ver. 98. Uses HBV parameter values for Chicken Creek from John Dalyrmple’s recent calibration of INFEWS using WillametteINFEWSdemo\_0.1.2 and uniform weighting, together with ET\_MULTIPLIER = 1.7.

CW3M\_ChickenCreekInstaller\_0.1.1.exe 12/12/18 84 MB made from CW3M ver. 105, saved in ver. 106. Renames ET\_MULTIPLIER to ET\_MULT, to facilitate use of the PEST program for calibration. PEST limits variable names to 12 characters. Includes CW3M Digital Handbook folder.

CW3M\_NSantiamInstaller\_0.1.2.exe 12/16/18 110 MB from CW3M ver. 113. Revise N. Santiam instream water rights per Joel Plahn at OWRD.

CW3M\_0.1.3\_Installer.exe 1/28/19 97 MB from CW3M ver. 129. Add Marys River watershed.

CW3M\_Installer\_0.2.0.exe 4/19/19 from CW3M ver. 155. Add options for including leapdays and for reporting on a water year basis. Accommodate multiyear NetCDF climate data files. Eliminate the need for monthly climate data. Add routines for accessing weather data by reach. Skip over reservoirs which are outside the study area when calculating the mass balance. Turn off the UpdateDGVMvegtype autonomous process. Incorporate the version of HBV.csv used in INFEWS. Add climate scenario 8, BaselineGridMultiyearFiles. Add logic for 5-column format for observation files which references the day number to 1/1/1900, to be used for observation files which include leapdays. Add support for running the parameter estimation program PEST on the Marys River study area.

CW3M\_Installer\_0.2.1.exe 4/19/19 from CW3M ver. 156. Add Marys\PEST folder with files to support use of the PEST parameter estimation program on the Marys River basin.

CW3M\_Installer\_0.2.2.exe 5/15/19 from CW3M ver. 160. Fix bugs in the logic which reads the climate data files. Add the new multiyear MIROC5 climate dataset as climate scenario 9 for the Marys basin study area. Add a new “MIROC5\_macav2” simulation scenario. These new scenarios aren’t working yet.

CW3M\_Installer\_0.2.3.exe 5/17/19 from CW3M ver. 162. Fix more bugs in the logic which reads the climate data files.

CW3M\_Installer\_0.2.4.exe 5/17/19 from CW3M ver. 172. Overhaul logic for reading multiyear climate data files, to speed up access to larger files. Add scenarios for macav2metdata MIROC5 and HadGEM-ES 1950-2005 and RCP 8.5 2006-99.

CW3M\_Installer\_0.2.5.exe 5/24/19 from CW3M ver. 176. Correct a bug which causes the Baseline scenario to fail.

CW3M\_Installer\_0.2.6.exe 6/3/19 from CW3M ver. 182. Fix bugs in IGet(), GetTimeIndex(), and GetDailyWeatherfield(). Get the MIROC5 and HadGEM-ES scenarios working. Add the 365dayBaseline scenario, which uses the old single-year MACA training data climate. Baseline uses the new multi-year v2metdata climate dataset, but there are still issues with it.

CW3M\_Installer\_0.2.7.exe 6/4/19 from CW3M ver. 184. Fix a bug in GetJulianDay() which was causing the 365dayBaseline scenario to crash in 2005. The Baseline and 365dayBaseline scenarios are both working now, but precip from the multi-year v2metdata climate files used by Baseline is higher than precip in the original single-year MACA training data climate files, so Baseline gives higher flows in the Marys River basin than 365dayBaseline does.

CW3M\_Installer\_0.2.8.exe 6/8/19 from CW3M ver. 186. Put in a workaround for the fact that the origin of the climate data grid in the multi-year v2 climate datasets is in the SW corner of the grid, but GDAL still calculates gridcell indices as if the origin were still in the NW corner as in the original single-year climate files.

CW3M\_Installer\_0.2.9.exe 6/14/19 from CW3M ver. 190. Enter HBV parameter values for HBVCALIB=23 Marys from the most recent calibration, but with all available digits of precision. Manually change K2 for HBVCALIB 23 from 0.000124 to 0.0006 to avoid a long term buildup of water in the slow flow groundwater compartment of the HBV model. Add files to allow for simulation of the complete Willamette River basin.

CW3M\_Installer\_0.2.10.exe 6/17/19 from CW3M ver. 194. Update Flow initial conditions files. The new files were made by spinning up the Marys and WRB with the BaselineGridMultiyearFiles climate dataset for 31 years (1979-2009), and by spinning up just the Marys River basin using the MIROC5\_20th\_century and HadGEM-ES\_20th\_century climate datasets for 56 years (1950-2005).

CW3M\_Installer\_0.2.11.exe was withdrawn because of errors in the script which created it.

CW3M\_Installer\_0.2.12.exe 12/10/19 from CW3M ver. 6 on GitHub. Includes the LOG\_Q attribute in the reach layer.

CW3M\_Installer\_0.3.0.exe 6/24/20 from CW3M ver. 16 on GitHub. Logic has been added to create the LOG\_Q and RH attributes in the reach layer, the GRID\_INDEX and RH attributes in the IDU layer, and the RH attribute in the HRU layer. Includes the data files for the McKenzie River basin, which have been updated to include the new attributes. Fix a bug in the “multirun” feature in the logic for running from a command line; this fix was contributed by Maria Wright on the OUWIN project. Comment out the maxDaysInYear specification in the CW3M\_McKenzie.envx file, and update the climate scenario specification in Flow\_McKenzie.xml. This version is the starting version for the Lane Council of Governments Wetlands project funded by the EPA.

CW3M\_Installer\_McKenzie\_0.3.1.exe 6/24/20 from CW3M ver. 17 on GitHub. An installer script has been added which includes the data for the McKenzie basin, but leaves out the data for the Willamette River basin outside the McKenzie basin.

CW3M\_Installer\_McKenzie\_0.3.2.exe 7/7/20 from CW3M ver. 25 on GitHub. Add the Clackamas basin. Get the McKenzie working with future climates. Add a Required Input page to the Data Dictionary.

CW3M\_Installer\_McKenzie\_0.3.3.exe 7/23/20 from CW3M ver. 27 on GitHub. Add and populate the WETL\_ID attribute in the McKenzie and Clackamas IDU layers. Add Wetlands.xlsx and the WW2100 PNAS paper to the CW3M Digital Handbook folder.

CW3M\_Installer\_McKenzie\_0.3.4.exe 8/1/20 from CW3M ver. 31 on GitHub. Add reports on wetland outflows and at the Hayden Bridge gage location. Populate the HBV.csv table for the lower McKenzie and for the Mohawk basin.

# References

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# Acronyms and Abbreviations

**cms** – cubic meters per second

**CW3M** – Community Willamette Whole Watershed Model

**EPA** – Environmental Protection Agency

**IDU** – Integrated Decision Unit, CW3M’s smallest 2-dimensial spatial unit of computation. IDU polygons tile the study area.

**gridMET** – “gridMET is a dataset of daily high-spatial resolution (~4-km, 1/24th degree) surface meteorological data covering the contiguous US from 1979-yesterday” <http://www.climatologylab.org/gridmet.html>

**HRU** – Hydrologic Response Unit

**LCOG** – Lane Council of Governments

**LULC** – land use land cover

**MOU** – Memorandum of Understanding

**SSURGO** – Soil Survey Geographic Database, from the Natural Resources Conservation Service - National Cartography and Geospatial Center

USACE – United States Army Corps of Engineers