CW3M Digital Handbook

Information about the Community Willamette Whole Watershed Model

7/1/20

CW3M is maintained by Oregon Freshwater Simulations Inc.

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Changes since 12/10/19 version

Add notes for 0.2.11, 0.2.12, 0.3.0, and 0.3.1 releases to the Release Log.

Add section on the McKenzie basin wetlands project.

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[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. 8](#_Toc10873622)

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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

Description automatically generated]()

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

Description automatically generated]()

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.

# 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 at the freezing point

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. The WaterParcel class can be extended to include other properties, such as sediment load and dissolved pollutants, but as of May 2019 those quantities are not modeled.

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

As of May 2019, this description of thermal energy calculation and tracking is aspirational; this functionality has not yet been fully implemented and tested. 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.

# Water temperature from thermal energy

The amount of thermal energy in the water in a reach or reservoir, referenced to zero energy 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)

# 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.

# Initial conditions for Flow

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.

# 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

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. The purpose of using CW3M in the 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 fSrom 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 model (Boyd & Kasper 2003) used by the Oregon Water Resources Department, to provide simulations of daily stream temperatures along with daily flows.

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. As of late June 2020, the McKenzie wetlands study is just getting underway.

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. HRUs are made up of IDUs; HRU boundaries are coincident with some of the boundaries of the IDUs of which they are composed. Zero, one, or several HRUs may drain to a single 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?).

# 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\_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.

# References

Boyd, M., and Kasper, B. 2003. Analytical methods for dynamic open channel heat and mass transfer: Methodology for heat source model Version 7.0. <https://www.oregon.gov/deq/FilterDocs/heatsourcemanual.pdf>

Cowardin, L.M. & Golet, F.C. US Fish and Wildlife Service 1979 wetland classification: A review. Vegetatio (1995) 118: 139. <https://doi.org/10.1007/BF00045196>

# Acronyms

**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 Resource Unit

**LCOG** – Lane Council of Governments

**LULC** – land use land cover

**MOU** – Memorandum of Understanding