Pond Inundation and Timing (Pond-IT) Model Guidebook: An Open-Source Hydroperiod Water Balance Model for Developing Climate-Adaptive Pond and Wetland Habitat Management Strategies

Model Version 1.2

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Balance Hydrologics

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1 EXECUTIVE SUMMARY

In Mediterranean and arid climates, seasonal ponds play important roles for native species, whose life cycles are often timed with the annual wet-up and dry-down period, or hydroperiod. With anticipated changes in climate, existing habitat may be affected by changing air temperature or precipitation patterns. Throughout much of California, properly managed anthropogenically-formed or -altered cattle ponds have the potential to be valuable aquatic habitat for endangered and target native species. To effectively manage these resources and prioritize conservation efforts, we pose two main questions: 1) Can the aquatic feature sustain habitat for a target species in the existing configuration? and 2) Can proposed modifications or enhancements create additional habitat that is resilient to changing climates? To answer these questions, we have developed a flexible, robust, and cost-effective Pond Inundation and Timing (Pond-IT) model to quantify relative importance of hydrologic drivers of hydroperiod in ponds which could serve as valuable habitat for many species, such as native frogs, salamanders, and turtles. The water balance model infers an estimated monthly balance between hydrologic fluxes of runoff, evapotranspiration, and groundwater, to develop a record of pond water-surface elevation. While this technique is not novel, most water-balance models require many years of monitoring data, which is expensive to acquire, especially in remote environments. In contrast, Pond-IT leverages increasingly available aerial photographs to collect model calibration data remotely, which is cost-effective and can span multiple decades. Development of a hydroperiod model requires only one field visit to obtain a bathymetric survey; the remaining model inputs rely upon free, publicly available datasets.

Pond-IT was initially developed using Python, an open-source programming language known for being both readable and customizable. This document serves as the technical guidebook for the general model framework, and also a step-by-step user-guide for both a Microsoft Excel and Python version of the model. We also present a genetic classification scheme for vernal pools (e.g. Pedogenic, Tectogenic, Landslide Head Scarp, etc.), which can be implemented easily using watershed-scale information such as underlying geology and soil types.

2 POND-IT LIMITATIONS AND TERMS OF USE

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Pond Inundation and Timing (Pond-IT); An Open-Source Hydroperiod Water Balance Model for Developing Climate-Adaptive Pond and Wetland Habitat Management Strategies

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Questions regarding Pond-IT should be directed to
pondit@balancehydro.com

or

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Berkeley, CA 94710

2.2 Limitations

The goal of a Pond-IT model is to understand the range of potential hydroperiods under existing conditions and, with a calibrated model, to efficiently explore a range of possible mitigation or restoration activities with the goal of creating or improving habitat for the target species. Other uses of the data, code, or model calculations have not been tested and may not be applicable for other applications. Use of the model is intended for planning-level design decisions and not intended for engineering or infrastructure designs. Although we recommend publicly available datasets to use as model input data in this guidebook, we make no guarantees about the quality or applicability of an input dataset to your application. Balance Hydrologics is not responsible for design or planning decisions that are made with Pond-IT model constructed by others, including but not limited to interpretations or conclusions, management decisions, validity of climate change projection datasets. This guidebook is intended to assist users with using Pond-IT correctly, but Balance cannot guarantee against incorrect uses.

Although the model has been tested in a range of environments and spatial and temporal scales, use of the Pond-IT model may not be appropriate in all hydrologic environments or for all projects. Please contact us at pondit@balancehydro.com if you have questions about the applicability of Pond-IT to your project or about the model results, or regarding opportunities to enhance or expand the model features and capabilities. We have documented commonly found error messages in this guidebook, but please also contact us if you have issues or questions running the model so can incorporate changes into future revisions of the model and accompanying documentation.

3 KEY TERMS

- Bathymetric survey: topographic survey data collected in the area under the pond water surface; collected via ground-based survey techniques as aerial surveys typically do not penetrate water.
- Dry-down: period in which a pond dries up after the cessation of rainfall.
- Evapotranspiration (ET): The process by which water is transferred from the land to the atmosphere either by direct evaporation from the soil or standing bodies of water, or by transpiration from plants.
- Genetic types: A classification system defined herein which groups ponds by the underlying geologic- and soil-based properties which contributed to the formation of the pond.
- Geomorphic: Relating to the form of the landscape and other natural features of the earth's surface.
- Hydroperiod: The annual time period at which a pond or wetland is inundated.
- Inundation: Flooding or rising and filling of water in a topographic depression.
- Input: Data which is used to parameterize the model, a "model input".
- Inflow: Water which flows into a pond, e.g. groundwater inflow.
- Outflow: Water which leaves a pond via the spillway, groundwater flow paths, or ET.
- Output: Data which is a result of the model, a "model output".
- Jupyter Notebook: An open-source web application that allows you to create and share live code, equations, visualizations, and text.
- Macroinvertebrates: An animal lacking a backbone and visible by the naked eye without the assistance of a microscope.

- Pond: a topographic depression which seasonally impounds standing water. In this document, also refers generically to seasonal wetlands, vernal pools, and stock ponds.

- Python: In this document, Python refers to the open-source programming language, not the snake.

- Runoff: Water from rain, snowmelt, or other sources that flows over the land surface.

- Spillway: Structure, often an earthen berm, which impounds water in a pond; Location at which inflowing water that exceed the pond capacity leaves the pond.

- Spilling surface runoff: Pond water which leaves the pond as incoming water supply exceeds the pond storage capacity; routed over the spillway.

- Water year: A hydrologic year beginning October 1st and ending September 30th; for example, water year 2019 is from October 1st, 2018 through September 30th, 2019.

- Water-balance (model): a model which quantifies the timeseries of hydrologic mass-balance (i.e. inflows minus outflows).

- Wet-up: period in which a pond fills.

4 PROJECT BACKGROUND

4.1 Problem Statement

Stock ponds, seasonal wetlands, and vernal pools (generically referred to as ponds herein) offer a wide range of habitat for both plant and animal communities across California and beyond. Increased urbanization and other land-use changes, as well as changing climate have impacted the natural hydrologic cycles of these ponds, often with detrimental impacts to the supported ecosystems. In the California Coast Range, many historical ranching and agricultural practices have preserved perennially-wetted stock ponds which can provide ideal habitat for non-native bullfrog (Rana catesbeiana), a key predator of native and critically impacted California Red-Legged Frog (Rana draytonii, CRLF). In the central valley of California, conversion of vernal pool complexes to agricultural land has endangered vernal macroinvertebrates (e.g. vernal pool fairy shrimp, Branchinecta lynchi) and rare vernal pool vegetation. The success of these specialized ecosystems is heavily dependent upon the duration of pond inundation, or hydroperiod, which is typically determined by the balance of rainfall, runoff, evapotranspiration, and groundwater inflows and outflows.

Persistence of pools in streams, ponds, and artificial impoundments through the long dry season is a key determinant of habitat availability and can be difficult to determine based on sporadic or short-term observations (Skidds and Golet, 2005). Quantifying hydrology of a pool of interest typically requires time-intensive monitoring or development of a model balancing these hydrologic fluxes. Calibration of such models is difficult to do well, as long-term monitoring of a pond is expensive and time-consuming, and acquisition of the data are rarely considered sufficiently in advance of the construction of the model. Scaled across landscapes with many pools, costs of collecting site-specific calibration data can escalate quickly.

Continued climate change threatens to alter the annual hydroperiod through an increase the intensity of storms and magnitude and duration of droughts, which may reduce and fragment available habitat through the reduction or elimination of key individual breeding and rearing pools and ponds.

4.2 Pond-IT, A Hydroperiod Water Balance Model

Balance Hydrologics (Balance), in collaboration with the Guadalupe Coyote Resource Conservation District (GCRCD) and with support from the Santa Clara Valley Habitat Agency (SCVHA) and the California Department of Fish and Wildlife (CDFW), developed the Pond Inundation and Timing (Pond-IT) model, a hydroperiod water balance model designed to optimize hydroperiod for CRLF in stock ponds in Santa Clara County, California (Donaldson et al., 2018). Pond-IT reconstructs historical water-surface elevations across a range of hydrologic conditions and can be easily extended past the calibration period and into the future using climate change projection data. To-date, Pond-IT has been used to evaluate and inform management of 36 water bodies within Santa Clara County. We utilize a numerically straight-forward water balance model, which has been implemented for a variety of landscapes and timescales, but with two novel methods for model calibrations.

First, with only a bathymetric survey of the pond, historical aerial imagery can be leveraged to compile historical model calibration data when depth monitoring data are not available. Each historical image is converted into a single calibration data point and repeat pond inundation area measurements form the historical calibration record. This calibration data can be supplemented with available pond monitoring data, and while not strictly necessary, even a few months of continuous pond depth monitoring can improve the model performance.

Second, we expand a genetic classification system following Bauder et al., (2009) to group pools with different geomorphic origins, which we call genetic types. Genetic classification type informs expected hydrologic behavior. For example, ponds located on or adjacent to faults are more likely to be groundwater supported. Ponds located on landslide head scarps typically form on relatively unconsolidated material and drain more quickly than pedogenic ponds, which form on deeply mature soils which tend to slow infiltration. When modeling a large ensemble of ponds, monitoring data can be collected in a representative subset of ponds and model parameters extrapolated to the larger pond population.

Genetic classification is different from other rapid assessment methods, such as the California Rapid Assessment Method (CRAM), which fundamentally establishes relative functions and values of pools using four attributes, landscape context, hydrology, physical structure, and biotic structure. CRAM is often used to value wetland functions in avoided ‘preserves’ or ‘buffers’ and is well suited to detecting changes (especially deterioration) of habitat in pools. CRAM is a one-time evaluative rubric for individual ponds, at a time when development of larger preserves with diverse origin and landscape processes are sought to better meet wetland restoration objectives over long-term hydrologic trajectories and changing climates. The genetic classification system presented here differs from CRAM by placing hydrologic processes into context of landscape-scale systems (e.g. geology, soils, topography) over long time-scales. On a regional scale, the preservation of the diversity of vernal pool, stock pond, and seasonal wetland habitats depends on the preservation of a diverse set of pond types, with varied hydroperiods, form, and function. This classification system has the potential to assist land managers prioritize pond diversity alongside species preservation and management.

4.3 Goals for this Manual

This guidebook has been developed to explain how to use the model, with a description and examples of appropriate applications that include discussion of model results and implications for the modeled hydrologic system.

4.4 Acknowledgements

This report has been a collaborative effort and so we would like to acknowledge several key contributors.

- Stephanie Moreno for development of the initial concept and bringing this project to us for discussion and effective co-development of the concept and application of the results of this study. We also appreciate her persistence in finding funding for the project and leadership and vision through the life of the grant.
- GCRCD Board of Directors for generously supporting this important work with the in-kind contribution of Stephanie Moreno's time.
- Edmund Sullivan (SCVHA) and Terah Donavan formally with SCVHA for assistance in developing the grant, and their generous in-kind contributions.
- Barry Hill, formerly of Santa Clara County Parks (SCCP), currently at Solano County Parks and Recreation Division, for initially conceiving of a scientific study in SCCP pond hydroperiods and allowing us to further develop his approach and execute a study.
- Don Rocha at SCCP for providing critical institutional knowledge and guidance during initial project discussions
- Michael Rhoades at SCCP for working closely and openly with the project team to complete the field data collection campaign and communicate the interests of the SCCP to the Team.

- GCRCD volunteer Gary Jahns, for his invaluable assistance with the field calibration data collection campaign.

- The SCCP Rangers who provided invaluable assistance with park access, historical observations, and insights into on-the-ground pond management.

5 POND-IT MODEL FRAMEWORK

The main purpose of the Pond Inundation and Timing (Pond-IT) model is to infer the dry-down timing across a range of hydrologic years and to extend the model into the future using climate projections. Pond-IT is a general water balance model that calculates the net of hydrologic inflows (precipitation, runoff, and groundwater) and hydrologic outputs (evapotranspiration, spilling surface runoff, and groundwater). Nearly all model input data is publicly available or can be derived using a desktop-based analysis; the only field visit required is to collect site-specific stage-storage (or capacity-area) information. The model can generally be computed in one of two ways: 1) predicted automatically using a numerical solver and available calibration data, or 2) iteratively calculated through manual refinement of model fit parameters (not recommended). Calibration data can be measured via aerial imagery (e.g. Google Earth) and supplemented with water depth observations if available. The model is computed using a monthly timestep which allows for seamless integration into the widely available monthly climate projection datasets and increased model efficiency and is often sufficient for most project objectives.

5.1 Model Inputs

This section provides a step-by-step guide on how to obtain input data specific to your study site and format it for use in the Pond-IT model. Keep in mind these are the datasets used for previously vetted model builds but you may have other data that is more appropriate for your project. Whatever datasets you choose to use be sure to format as described below so that input data can be loaded properly into Pond-IT.

Note: Whatever datasets you choose to use be sure to format as described below so that input data can be loaded properly into Pond-IT. Alternatively, you can simply modify the example input files to use with your input data (preserving column names and general formatting).

Table 5-1 summarizes all the required model inputs, required column names, and file formats.

Table 5-1 Summary of Model Input Data

<table>
<tr><th>Input Dataset</th><th>Required column names (listed in order)</th><th>Python Model Input File Format</th><th>Excel Model Input File Format</th></tr>
<tr><td>Historical Climate Data</td><td>- date
- precip_in
temp_mean_C</td><td rowspan="3">File Format rules:
- '.csv extension;
- make different files for each modeled location;
- column names must match exactly (including case) but can be in any order, extra columns are permitted but will be ignored</td><td rowspan="7">File Format rules:
- '.xlsx, .xls, or .csv file extension;
- columns must be in order listed</td></tr>
<tr><td>Projected Precipitation</td><td rowspan="2">- year
- month
-date
- GCM name (values are precipitation or temperature)</td></tr>
<tr><td>Projected Air Temperature</td></tr>
<tr><td>Watershed Soil Characteristics</td><td>- Depth Weighted Water Capacity
- Percent of AOI
- Thickness (inches)</td><td rowspan="4">File Format rules:
- '.xlsx extension;
- for running multiple models using Python Pond-IT, make multiple sheets for each pond;
- column names must match exactly (including case) but can be in any order, extra columns are permitted but will be ignored</td></tr>
<tr><td>Model Calibration Data (Area)</td><td>- date
- area_sqft</td></tr>
<tr><td>Model Calibration Data (Elevation)</td><td>- date
- elev_ft</td></tr>
<tr><td>Stage-storage</td><td>- elev_ft
- area_sqft
- storage_cuft</td></tr>
</table>

The following sections explain each model input in more detail.

5.1.1 Historical Climate Data

Unless another preferred historical dataset is available, historical monthly air temperature and precipitation can be sourced from the University of Oregon PRISM Climate Group (hereafter, 'PRISM')[1]. Download the data for the period you wish to model plus an earlier 5 years for use as model initialization period. The model starts with the pond completely dry and so take several years of simulation to "spin up." Considerations for deciding the historical model period include:

[1] http://www.prism.oregonstate.edu/explorer/

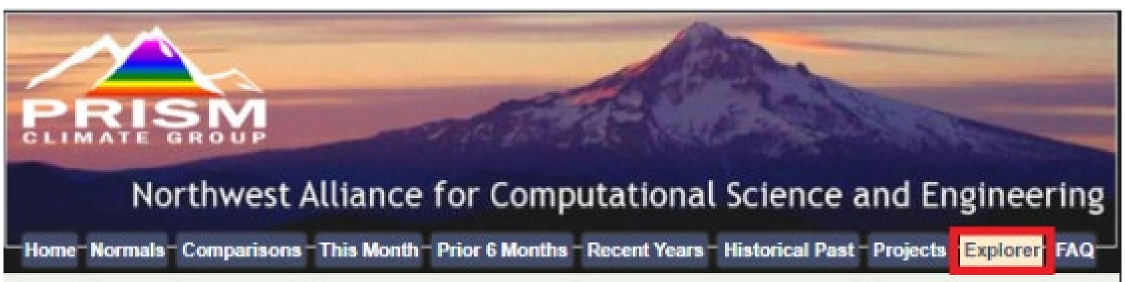
- The pond or contributing watershed should be relatively free from disturbances during the analysis period. For example, pond storage changes due to sedimentation, relative to berm construction or failure, etc. may make model results not applicable.
- Several of the groundwater model modules use annual total precipitation metrics by water year, so if you intend to use a partially-complete water year for the last few months, your model may produce odd results in the partial water year, particularly if your model period is missing a significant portion of the annual total rainfall. To mitigate for this, you can either model only complete water years, or extend the historical record with a few months of projected data.

Note: The historical model build will automatically end with the last month of provided historical climate data.

PRISM Data Download Example: Water 1975 through Present

Download historical data starting with water year 1975[2] (WY1975), starting with October, 1975:

1. On the PRISM website, navigate to the **Explorer** tab.



2. Find your study site via the **map**. **Click** on the **grid** that is relevant to your project. If the study area watershed is larger than one grid cell, additional processing will be required to combine the data to be most representative of the study watershed.
3. Under the **Data settings** → Select (a) **precipitation** and (b) **mean temp**.
4. Select **Monthly values** → Use the scroll down options to select

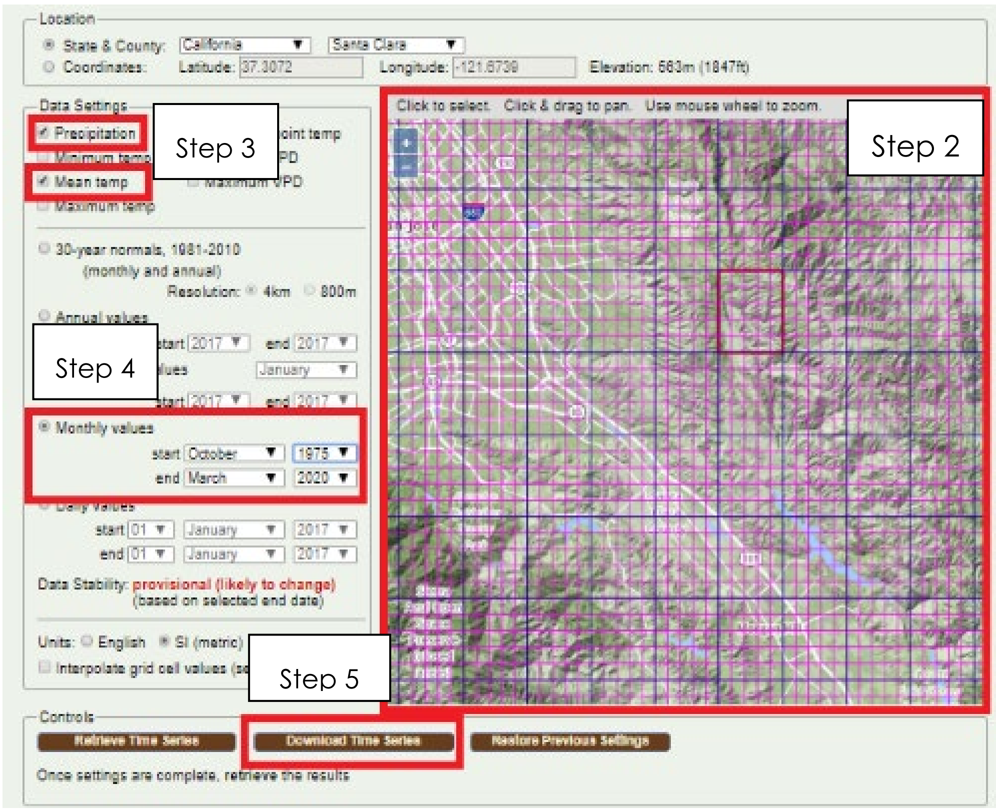
[2] A water year runs from October 1 of the preceding year to September 30, of the year for which it is named. For example, water year 1975 extends from October 1, 1974 to September 30, 1975.

   a. start = **October, 1975**

   b. end date = present date.

5. Under **Controls** → press **Download Time Series**.

6. Under **Units** choose **English**



7. **Convert** air temperature from Fahrenheit to Celsius which is required for the calculation of evapotranspiration in the model. Precipitation data is already in the required units of total inches per month.

8. **Note** – When downloading data from PRISM, the first 10 header rows will contain metadata for the data download request. These rows must be deleted before bringing the data into Pond-IT. Additionally, the default date format from PRISM will be YYYY-MM as plain text. This will need to be converted to a date in excel in the format. Sometimes Excel incorrectly interprets the PRISM date format differently pre- and post- 2000, so be careful when reformatting.

The final Historical Climate Data should be formatted as below:

	A	B	C
1	date	precip_in	temp_mean_C
2	10/1/1975	1.84	14.5
3	11/1/1975	0.29	10.66666667
4	12/1/1975	0.26	9.722222222
5	1/1/1976	0.16	10.27777778
6	2/1/1976	1	9.166666667
7	3/1/1976	2.15	9.888888889
8	4/1/1976	1.02	10.77777778

5.1.2 Projected Climate Data

A wide range of projected climate data is publicly available for download and use from a variety of sources. It is important to consider the most applicable climate projection dataset for your hydrologic environment, study question, and project objective. There are several key parameters to consider when choosing a climate projection dataset:

Representative Concentration Pathway (RCP)

Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory which represents one of four possible carbon concentration scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC). The four trajectories are characterized by the CO_2 concentrations in radiative forcing projected for the year 2100 based on a range of global climate change adaptation strategies. They are:

- RCP 2.6: Carbon emissions peak in the mid-century and then decline; best-case scenario that is frequently discarded as a likely RCP based on current emission trajectories.
- RCP 4.5: Characterized by emissions which stabilize by 2100; often used as the "best-case" scenario when RCP 2.6 considered unlikely.
- RCP 6.0: Characterized by emissions which stabilize after 2100 and have a late-century radiative forcing higher than RCP 4.5.

- RCP 8.5: Carbon emissions increase continuously over time; the "worst-case" RCP representing the highest greenhouse gas concentration levels.

Depending on the study question evaluated, modeling the hydroperiod of multiple RCPs may be valuable, particularly to evaluate the range of likely hydrologic responses given the uncertainty in climate projection datasets.

Coupled Model Intercomparison Project (CMIP) and General Circulation Models (GCMs)

The coupled model intercomparison project (CMIP) is a collaborative network established by the World Climate Research Program to collate and assess global climate projection data. CMIP has released a series of climate projection datasets based on the latest information available. CMIP5, released in 2013 is the latest generation of climate project models which has been vetted by the climate change community at large. Each CMIP phase produces a number of general circulation models (GCMs) which are derived using a range of baseline assumptions, initial conditions, and outcomes. The results of different GCMs are often used as an ensemble to represent average anticipated climate conditions. Because climate change projections are inherently uncertain, a set of GCMs can also be used to represent a range of likely outcomes and a dataset for which statistical trends can be calculated. Cal-adapt has identified 10 models for use in the state of California, with four identified as priority models and which represent a particular outcome. They are:

- HadGEM2-ES (warm/dry)
- CNRM-CM5 (cooler/wetter)
- CanESM2 (average conditions)
- MIROC5 (compliment – most unlike the other three models)

CMIP5 has 37 total GCMs, often with several parameter realizations representing additional possible outcomes. Not all GCMs are available for all four RCPs.

Selecting Climate Data

Selection of appropriate climate dataset is very important to the interpretation of the impacts of climate change on the pond hydroperiod. Often, a climate projection dataset will have significantly different climatological characteristics (e.g. average air temperature) in the historical modeled time period compared with the observed historical dataset. This is sometimes a result of differences in model scale – GCM grid cells can sometimes be larger than the dominant climate processes. For example, coastal fog can be a very small-scale and local process which significantly alters air temperature that may not be represented in all climate projections. There are several strategies that may be appropriate for use in Pond-IT hydroperiod model development, depending on your particular use case and project objective:

1. If long-term hydroperiod averages are desired, all available GCMs can be averaged; this produces a climate projection dataset absent any inter-annual variability, but clear long-term trends.
2. If a probabilistic interpretation is desired (e.g. percent likelihood of a particular hydroperiod), the model can be run for any number of climate projections and the results used to frame the range and frequency of potential outcomes.
3. A small number of GCMs (or even just one GCM) can be used when project objectives or goals identify a clear choice but should not be decided arbitrarily as the applicability of a climate projections dataset to your project area may vary depending on climate model parameterization.

Note: Projected climate data should be downloaded to overlap for some (or even all) of the historical period so that you can evaluate consistency between the datasets. The easiest way to do this is to plot historical and projected temperature and precipitation data.

Downloading Climate Projection Data

Climate projection data is available from a number of sources. To construct a Pond-IT model, your climate data must include monthly average air temperature (in degrees Celsius) and monthly total precipitation (in inches). If no other preferred dataset is available, you can download down-scaled CMIP3 and CMIP5 projected climate change data from the here:

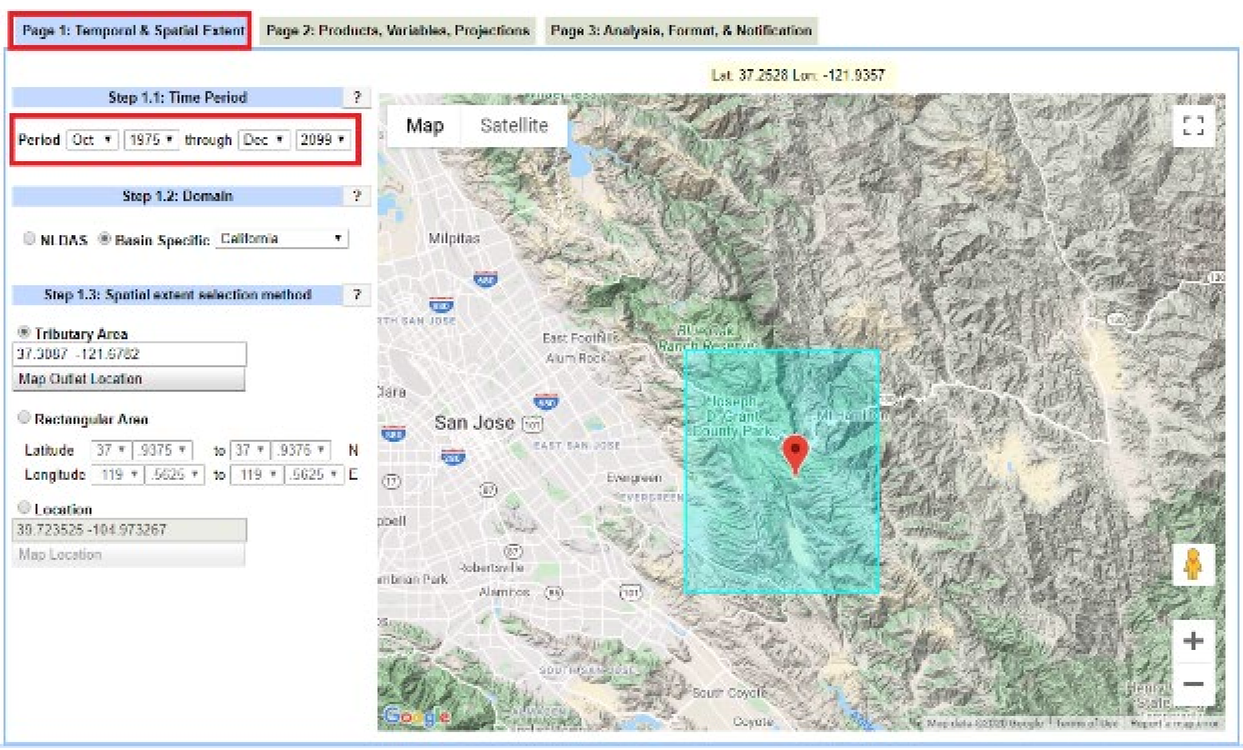
- https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#Projections:%20Subset%20Request

> **Note: Precipitation data downloaded from this source is in mm per day and needs to be converted to inches per month for use in the model.**
>
> To get the number of days in the month from a date use the following formula =DAY(EOMONTH(A1,0)), where A1 is your date cell

This website provides access to downscaled global climate projections from the World Climate Research Programme including the multi-model datasets Coupled Model Intercomparison Project (CMIP3) was released in 2010 and CMIP5 was released in 2013. Bias-corrected spatially disaggregated (i.e. "downscaled") data is available for download at 1/8-degree spatial resolution.

As an example, you can follow these steps to download all available downscaled CMIP5 GCMs for RCP 8.5 by following these steps:

1. Start on **Page 1: Temporal & Spatial Extent**
   a. Step 1.1 change period to **October 1975 through December 2099**.
   b. For Step 1.2/1.3 → Use the map interface to scroll to your project site → **double click** on the study site to highlight spatial extents

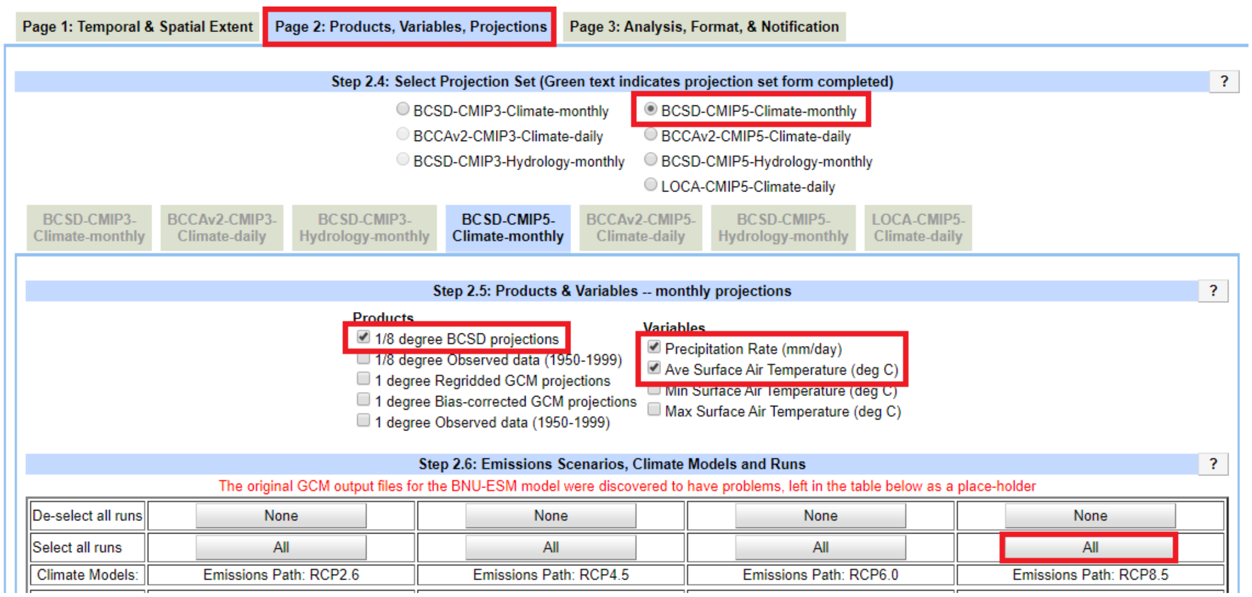


2. Navigate to **Page 2: Products, Variables, Projections**

   a. Step 2.4 → Select **BCSD-CMIP5 – Climate- monthly**

   b. Step 2.5 → Under Products → select (1) 1/8-degree BCSD projections; (2) Precipitation Rate (mm/day); and (3) Ave Surface Air Temperature (deg C)

   c. Step 2.6 → Under **Emission Path RCP8.5** → Press **All** button to select all variables. Note – RCP8.5 is the "worst-case" scenario. Depending on your project other RCP pathways may be selected.



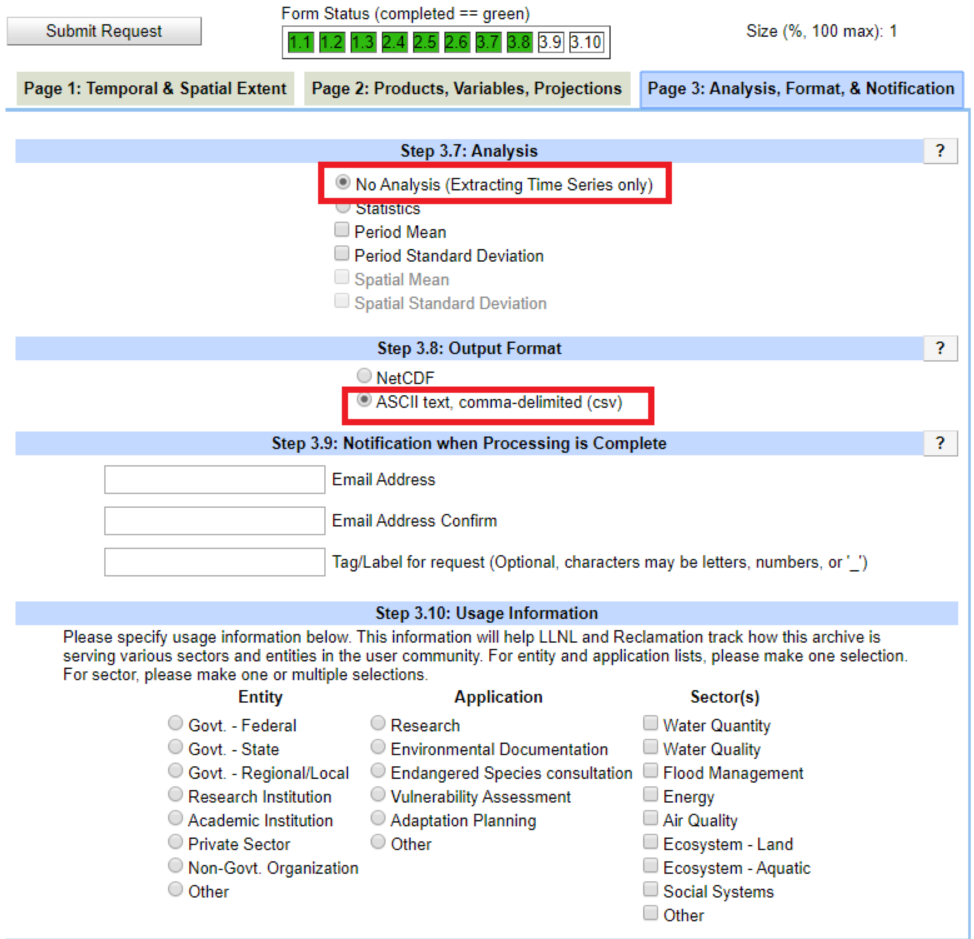
3. Navigate to Step 3: Analysis, Format, & Notification

   a. Step 3.7 → select **No Analysis**

   b. Step 3.8 → select **ASCII text, comma-delimited (csv)**

   c. Step 3.9 → fill in your email address → press **Submit Request** in the upper left-hand corner

   d. Step 3.10 → select industry that best fits your organization



4. The data are sent via email, which contains a link to a file archive. Inside the file archive is a zip folder which contains the requested data. There are two .csv files, one for pr (precipitation) and on for tas (air temperature). The files have many columns with no headers. There is a separate file in the archive with the column headers which needs to be inserted in excel. Final projected precipitation and air temperature data should be saved with

    a. Column **A** → Year

    b. Column **B** → Month

    c. Column **C** → Date

    d. Column **D and on** projected climate change variables downloaded

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	year	month	date	access1-0.1.rcp85	access1-3.1.rcp85	bcc-csm1-1.1.rcp85	bcc-csm1-1-m.1.rcp85	canesm2.1	canesm2.2	canesm2.3	canesm2.4	canesm2.5	ccsm4.1.rc
2	1975	10	10/1/1975	16.969	16.885	17.546	19.532	19.837	19.789	16.51	16.698	16.89	17.651
3	1975	11	11/1/1975	12.359	11.714	13.063	12.038	15.349	11.999	11.485	10.525	14.05	11.595
4	1975	12	12/1/1975	11.203	8.168	8.277	11.314	10.109	12.424	9.16	8.891	11.704	8.913
5	1976	1	1/1/1976	8.45	7.536	10.624	9.555	9.621	8.979	8.102	9.096	11.528	8.814
6	1976	2	2/1/1976	9.781	9.447	12.299	9.666	8.327	10.131	10.437	9.318	9.573	11.021
7	1976	3	3/1/1976	11.471	8.756	12.631	9.283	11.996	9.341	8.693	12.026	12.04	10.231
8	1976	4	4/1/1976	11.461	12.528	13.802	14.318	15.327	14.921	13.736	15.317	11.986	13.598
9	1976	5	5/1/1976	17.509	15.929	16.052	19.422	17.942	19.918	15.769	16.6	16.469	14.014
10	1976	6	6/1/1976	18.649	20.229	18.806	22.164	19.785	20.799	19.737	22.57	21.457	20.407
11	1976	7	7/1/1976	25.521	25.662	25.144	25.725	25.316	25.94	24.169	25.018	25.147	23.516
12	1976	8	8/1/1976	23.786	25.146	24.665	26.486	25.318	25.085	24.178	24.769	25.315	24.178
13	1976	9	9/1/1976	20.573	23.401	21.303	21.957	23.038	20.959	22.258	21.578	21.472	23.058

5.1.3 WATERSHED SOIL CHARACTERISTICS

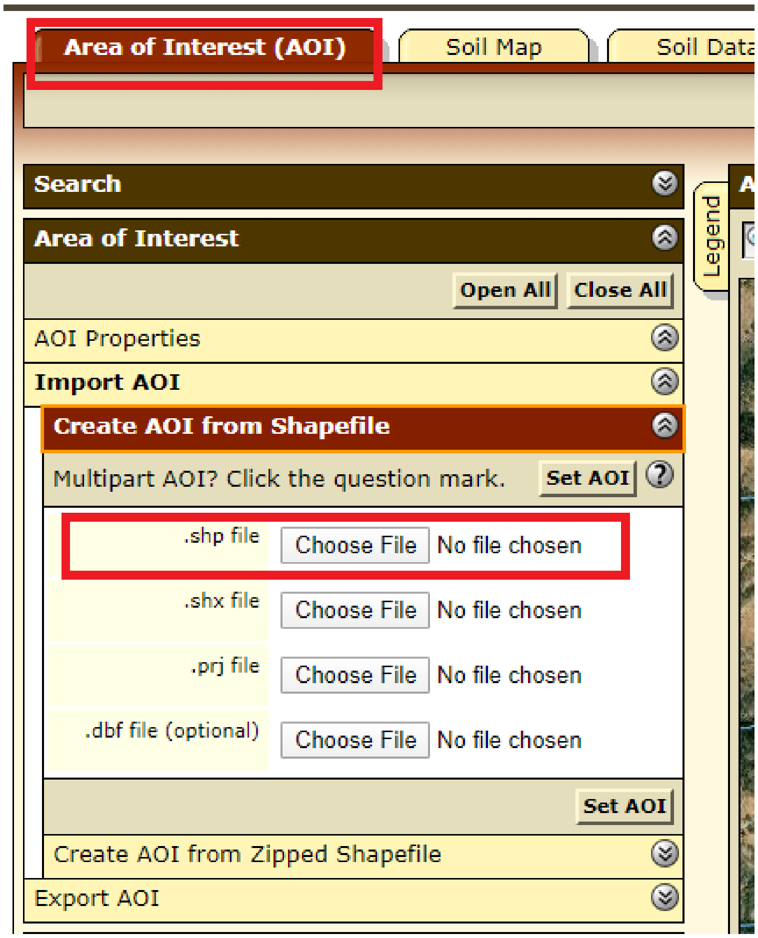
Key soil parameters used in the model are representative soil water capacity in inches per inch and soil depth which is used to calculate the soil moisture storage capacity in the watershed.

Unless another soil dataset is available, soil data for contributing watershed can be sourced from the National Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO). A depth-weighted water capacity is calculated across the soil profile thickness. If multiple soil types are located in a single watershed, the water capacity is spatially averaged in addition to depth-averaged. The standard model input is calculated using soil characteristic data from each of the soil types found within the contributing watershed, with one row per soil type.

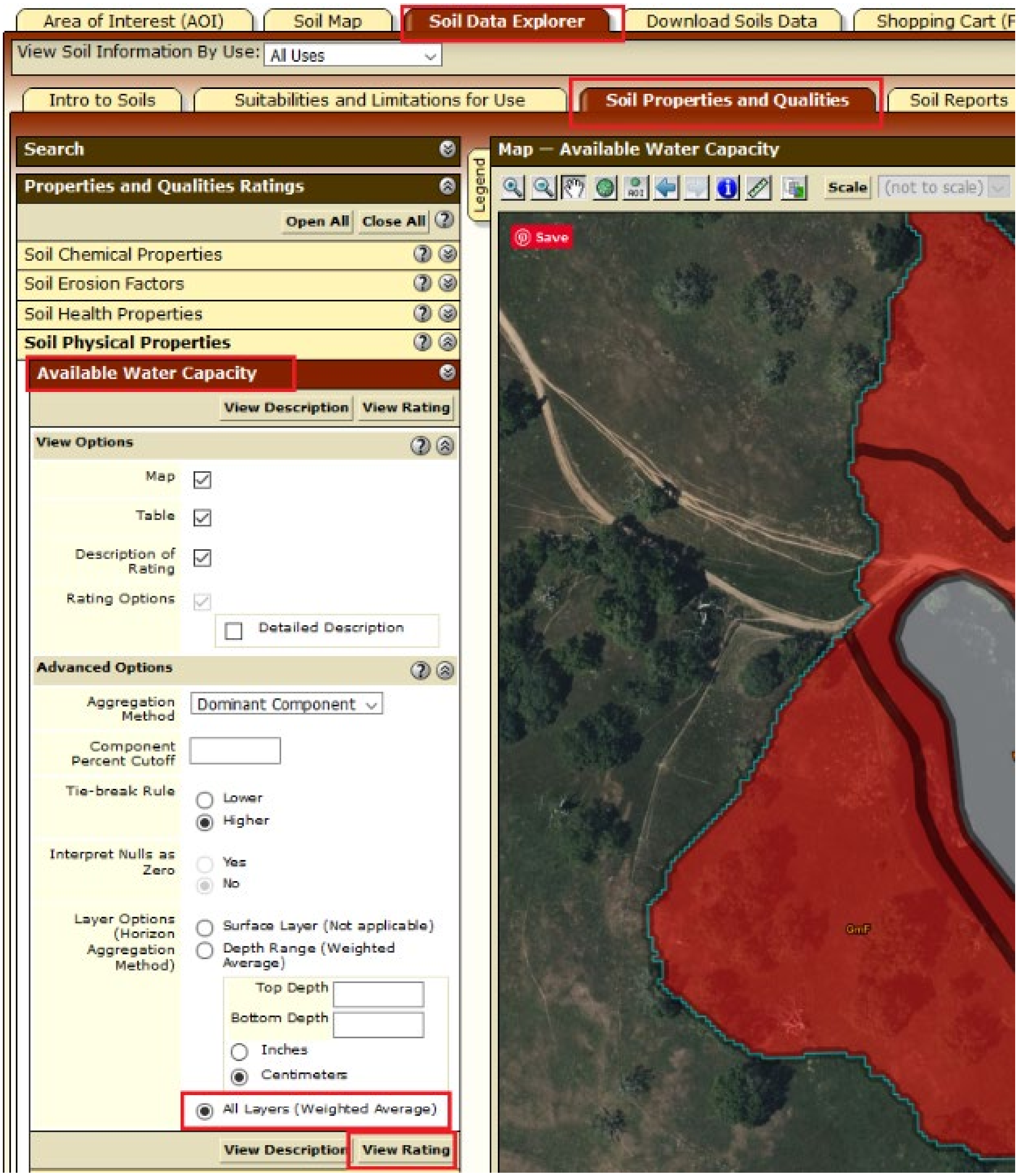
1. Navigate the NRCS Soil Survey interactive website→ click **Start WSS**: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

2. Click on the **Area of Interest (AOI)** tab → Area of Interest drop down arrow → Import AOI → **Create AOI from Shapefile** → navigate to your watershed shapefile created in Section 5.1.6.

> **Note: You can manually draw an AOI in the web soil survey if a shapefile is unavailable.**



3. Navigate to **Soil Data Explorer tab → Soil Properties and Qualities → Soil Physical Properties → Available Water Capacity → Advanced options → All Layers (Weighted Average) → View Rating**



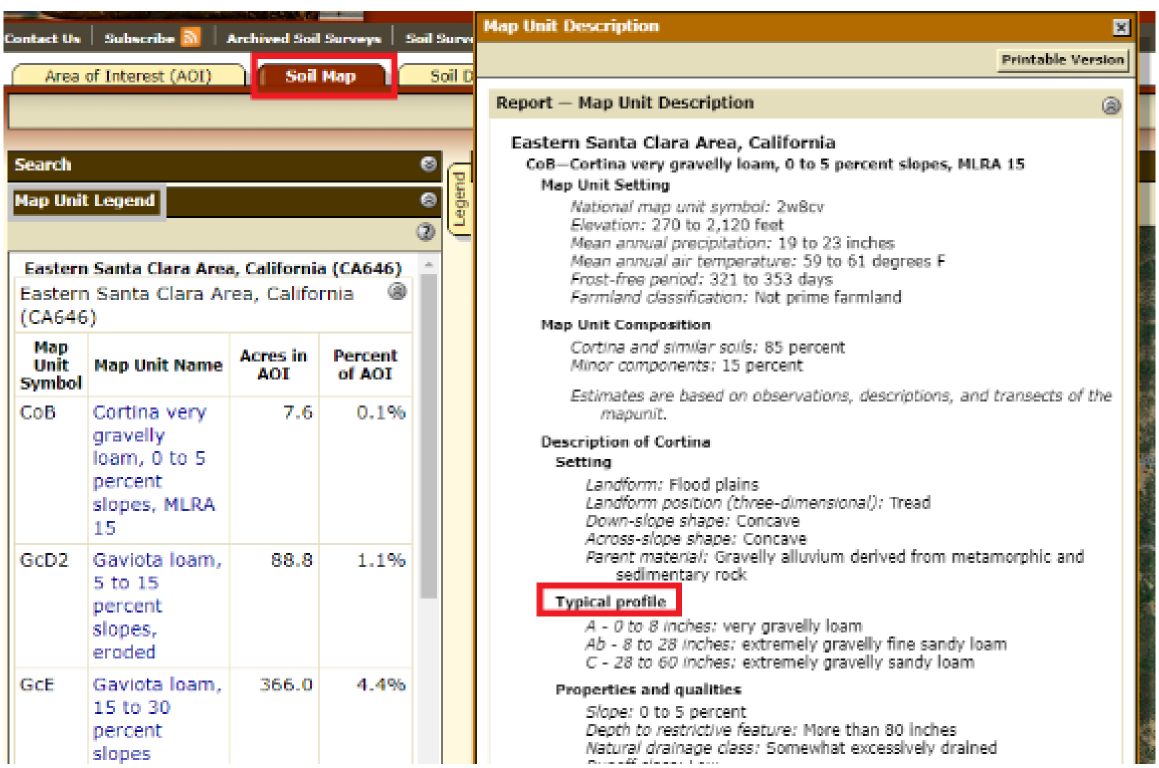
4. Scroll down to Tables – Available Water Storage – Summary by Map Unit → **highlight** table and **copy** directly into the an excel spreadsheet. The table should now be columns A thru E in the spreadsheet.

Tables — Available Water Storage — Summary By Map Unit

Summary by Map Unit — Eastern Santa Clara Area, California (CA646)

Map unit symbol	Map unit name	Rating (centimeters)	Acres in AOI	Percent of AOI
CoB	Cortina very gravelly loam, 0 to 5 percent slopes, MLRA 15	3.74	7.6	0.1%
GcD2	Gaviota loam, 5 to 15 percent slopes, eroded	6.15	88.8	1.1%
GcE	Gaviota loam, 15 to 30 percent slopes	7.22	366.0	4.4%
GcG	Gaviota loam, 30 to 75 percent slopes	7.22	2,084.0	25.2%
GhG2	Gaviota gravelly loam, 30 to 75 percent slopes, eroded, MLRA 15	7.23	184.8	2.2%
GhG3	Gaviota gravelly loam, 30 to 75 percent slopes, severely eroded	3.61	1,310.6	15.9%
GmF	Gaviota-Los Gatos complex, 30 to 50 percent slopes, MLRA 15	9.94	1,393.7	16.9%
HeG3	Henneke rocky clay loam, 30 to 75 percent slopes, severely eroded	3.22	182.9	2.2%
LhG	Los Gatos-Gaviota complex, 50 to 75 percent slopes	11.86	1,863.2	22.6%
LoF	Los Osos clay loam, 30 to 50 percent slopes	13.21	4.8	0.1%
LoG	Los Osos clay loam, 50 to 75 percent slopes	13.21	23.4	0.3%
PfG	Parrish gravelly clay loam, 50 to 75 percent slopes	14.05	84.9	1.0%
VaF2	Vallecitos rocky loam, 15 to 30 percent slopes, eroded	7.35	346.5	4.2%
VaG2	Vallecitos loam, 30 to 75 percent slopes, eroded, MLRA 15	6.50	305.4	3.7%
W	WATER		1.3	0.0%
YaB	Yolo loam, 0 to 8 percent slopes, MLRA 15	27.00	10.7	0.1%
Totals for Area of Interest			8,258.6	100.0%

5. Fill in column G with Profile Thickness. Navigate to **Soil Map tab → Map Unit Legend** → click on each **individual map unit name** → in the map unit popup window → look at the **typical profile**. Manually fill in the column with thickness of soil up to 60 inches.



6. Final soils data should be saved with:

    a. Column A→ Depth Weighted Water Capacity

    b. Column B → Percent of AOI

    c. Column C → Profile Thickness (inches)

	A	B	C
1	Depth Weighted Water Capacity	Percent of AOI	Profile Thickness (inches)
2	0.15	28.70%	20
3	0.15	58.40%	20
4			

Note: If your data contains an entry for "water" or other non-soil layer you may delete those data, your Percent of AOI column will not add up to 100% but is considered in the model.

5.1.4 Model Calibration Data

As with most water balance models, Pond-IT calculates several hydrologic parameters using easily available datasets (e.g. ET using air temperature, runoff using ET and precipitation, etc.). However, groundwater flux into and out of a pond is not easily computed or measured. So, the model finds the best solution for groundwater flux, calculated over several timescales, using a set of provided calibration data. This can be obtained in one of two ways. The first is via pond area data which is then converted to pond volume using the stage-volume-area, or stage-storage relationship (see Section 5.1.5). The second calibration dataset can be elevation-based data measured at various times using water level instrumentation or discrete observation of pond water depth using a staff plate or other device. Elevation or depth data is also converted to volume using the stage-storage relationship.

Note: Only one calibration data type is required to run the model. To skip one calibration type (area or elevation) you should still prepare the input file with the correct column names and file format, but you should leave the data rows blank.

The model will accept one or both types of calibration data. The model results will be most descriptive of the hydrologic processes and best predict climate change impacts if calibration data spans a range of water depths and wet and dry years. There are no minimum number of calibration points, but calibration data should represent a full range of pond depths, from full to dry, and across a number of different water year types.

Model Calibration Data: Pond Area

If aerial imagery of the pond is clear of obstructions and provides a clear view of the wet-dry boundary, pond area calibration data should be measured for available historical imagery spanning as many years in the past as possible.

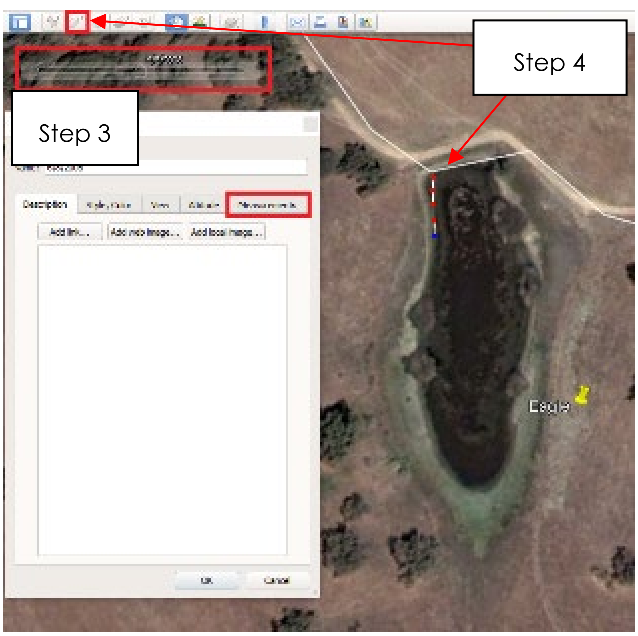
While reviewing the historical imagery, however, be sure to look for evidence of sedimentation or significant re-grading efforts or other alterations which would have materially affected the stage-storage relationship of the pond. Any calibration data collected prior to pond capacity alterations would not be applicable to the existing stage-storage relationship and so should not be used. In the right environment, slow but constant sedimentation will typically decrease the storage capacity of a pond gradually over time. Over the short-term (decade scales), we have not found this to make a significant difference in the model results. However, area-derived calibration data should be limited to a timescale in which significant sedimentation has not occurred. This timescale will vary for each pond, but we recommend using no more than approximately 20 years of historical aerial imagery data, even if available in the past.

The following is a description of steps for collecting pond area calibration data using Google Earth® historical aerial imagery.

Ponded area can be measured in each aerial image where the wetted boundary is clearly defined and observable. When drawing pond boundaries, some judgment is used to define pond water surface through stands of cattail or tule, or with interpretations of floating aquatic vegetation or algae around the pond edges. The use of Google Earth® historical imagery proved to be a powerful and cost-effective approach to calibrate and validate modeled long-term historical pond hydroperiod records.

1. Open **Google Earth®** → navigate to your project area
2. Click on **historical imagery icon** (bottom left hand corner of map)

3. Scroll through historical photos → choose dates where the wetted boundary is clearly defined and observable.
4. For each aerial image → click **Add polygon** → manually trace wetted area boundary. Once tracing is complete → click on **Measurement tab** → **record area** in an excel spreadsheet. Save polygons to be used in creating stage-storage relationships (Section Pond Stage-Storage-Area5.1.5).



5. Final area calibration data should be saved with the following format:

a. Column A → Date

b. Column B → Area (square feet)

	A	B
1	date	area_sqft
2	5/9/2018	32994
3	4/5/2016	33668
4	2/23/2014	4200
5	2/15/2012	28860
6	9/11/2011	26397
7	6/7/2011	32600
8	9/28/2010	17488
9	6/29/2007	33664
10		

Note: Delineation of the inundated or wetted area may require some interpretation as pond fringe vegetation can make the inundated area difficult to detect accurately.

Note: A dry pond should be included in area calibration data and correspond to the area indicated in the stage-storage relationship that corresponds to the pond bottom (that may be zero area).

Model Calibration Data: Pond Elevation

Pond elevation is typically sourced from available field data and either collected with depth measurement sensors or manual observations using a staff plate. Elevation data should be expressed in units of feet and can be reflected as either:

(a) georeferenced water surface elevation (WSE): Surveyed using RTK GPS or total station and tied into NGS (National Geodetic Survey) benchmark

(b) arbitrary WSE: arbitrary datum set using an auto-level or total station

(c) relative pond depth

Note that the stage-storage relationship must use the same vertical datum as the calibration data.

1. Final elevation calibration data should be saved as .xlsx, .xls, or .cvs with

    c. Column A → Date (closest month start date, the first of the month)

    d. Column B → Water elevation (feet)

	A	B	C
1	date	elev_ft	
2	2016-12-01	5.73	
3	2017-01-01	8.69	
4	2017-02-01	11.41	
5	2017-03-01	11.83	
6	2017-04-01	11.82	
7	2017-05-01	11.45	
8	2017-06-01	10.85	
9	2017-07-01	9.99	
10	2017-08-01	9.06	

5.1.5 Pond Stage-Storage-Area

Note: Pond Stage-Storage-Area data should include the full range of potential values, including the spillway elevation, pond bottom, and all calibration data values.

To convert between area- or elevation-derived calibration data and pond volume a stage-depth-area relationship (i.e. stage-storage relationship) is required for each modeled pond. An accurate stage-storage relationship is required to properly convert depth- and area-derived calibration data to a pond volume and so the best available information should be used.

Because model fit is dependent on calibration data that is converted to pond storage volume using the stage-storage relationship, the most accurate representation of pond capacity is recommended. This typically involves a ground-based survey to measure the topography of the pond being analyzed.

Pond stage-storage relationship can be calculated from high resolution Digital Elevation Model (DEM) surfaces using drafting or geospatial software. A physical survey (RTK GPS and/or total station) may be needed to acquire an accurate depiction of pond bathymetry. Depending on your geospatial resources one or more of the programs below will be helpful for you to calculate stage-storage relationships:

AutoCAD Civil3D: Use Surface Stage Storage Volumes workflow. Click **Analyze** tab → **Design** panel → **Stage Storage**

https://knowledge.autodesk.com/support/civil-3d/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Civil3D-UserGuide/files/GUID-9D5C80FA-EF92-4102-BCDC-37F0E04F591D-htm.html

ESRI ArcMap: 3D analyst (license required) toolbox workflow.

Extract by mask → 3D analyst toolbox (need license) → **Surface Volume** tool.
https://desktop.arcgis.com/en/arcmap/latest/tools/3d-analyst-toolbox/surface-volume.htm

ESRI ArcMap: Workflow using HEC-GeoRAS.

Download and load HEC-GeoRAS plugin → follow manual step-step tutorial. **RAS Geometry → Storage Areas → Elevation-Volume Data**.
https://www.hec.usace.army.mil/software/hec-georas/documentation/HEC-GeoRAS42_UsersManual.pdf

ESRI ArcMap: Spatial analyst toolbox (license required) workflow. For major contours, use a combination of DEM of difference using **Raster calculator and** calculate volume using **Zonal Statistics** (both in Spatial analyst toolbox).

QGIS (GRASS GIS): Open source geographic information system (GIS) software. Either use user-created plugins or use **Raster terrain analysis → Hypsometric curves** to calculate elevation and area relationships for your DEM surface. Additionally, volumes can be calculated using a similar workflow as in ArcMap using **Raster calculator and Zonal statistics.**

1. Final elevation calibration data saved with
    a. Column A → Elevation (ft)
    b. Column B → Area (square feet)

c. Column C → Volume (cubic feet)

	A	B	C
1	elev	area_sqft	storage_cuft
2	0	32.9	0.00
3	0.5	232.00	58.71
4	1	1,302.21	406.02
5	1.5	3,234.82	1504.26
6	2	5,653.04	3698.29
7	2.5	9,109.17	7354.65
8	3	15,508.24	13438.48

5.1.6 Watershed Area

Watershed area is a required model input used as a single number, calculated in square feet. See the corresponding sections below for constructing the Excel or Python model for how to enter this data.

Watershed area can be calculated using Lidar or high resolution DEMs and then refined based on field observations of flow paths around roads, berms and other structures. Several methods of calculating watershed area are available. Depending on your geospatial resources, one or more of the programs below will be helpful for you to calculate watershed area:

ArcGIS: ESRI suite of geospatial processing programs → Spatial analyst toolbox (need a license) → hydrology toolset. https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/an-overview-of-the-hydrology-tools.htm

HEC-GeoHMS: ESRI ArcGIS→ Download HEC-GeoHMS plugin. https://www.hec.usace.army.mil/software/hec-geohms/

QGIS (GRASS GIS): Open source geographic information system (GIS) software. Either use user created plugins or manually walk through an approach that mimics the hydrology toolbox in ArcGIS. https://docs.qgis.org/2.8/en/docs/training_manual/processing/hydro.html

StreamStats: A web application hosted by USGS providing a variety of GIS analytical tools including a map-based interface to delineate watershed area. https://streamstats.usgs.gov/ss/

Once you have delineated your watershed you can save the resulting boundary to a shapefile (.shp format). The watershed shapefile can be used in Section 5.1.3 to identify the extent of the soils data needed. You will also need to calculate the watershed area in square feet as an input to the model. If you do not have a GIS application, you can use StreamStats to calculate the watershed area.

Note: an alteration in watershed size from the initial watershed area calculation may be applicable when highly fractured watershed subsurface runoff pathways differ from the surface topography.

5.1.7 Other Model Input Parameters

In addition to the above model input parameters, you are also required to input the following:

- pond spillway elevation in the same vertical datum as the stage-storage and calibration data
- Pond location latitude in decimal degrees (used for ET calculation)
- Watershed area in square feet (see previous section for more details)
- CIMIS ETo zone (an integer between 1 and 18), to specify the reference evapotranspiration zone (Appendix A)
- Target inundation depth, to calculate the projected inundation probability; entered in feet as relative water depth and not elevation

These parameters are entered in a separate file and are discussed in more details in the Excel and Python model Sections 6.2 and 7.3.1 below.

5.2 Model Fit Parameters

Pond-IT was designed with the capability to estimate model-fit parameters based on user-provided calibration data (Table 5-2). Model parameters are optimized using a numerical solver to minimize the sum of the mean squared error between the model results and calibration data. These model fit parameters can be adjusted when specifying the initial conditions; see Sections 6.2 and 7.3.1 below. A cartoon schematic of the modeled hydrologic input/output is shown in Figure 5-1.

Table 5-2 Summary of Model modules, model fit parameters, names, and units.

	Model Module	Model Fit Parameter (Excel Model)	Python Variable Name	Min	Max	Units
Inflows	Direct Rainfall	Rainfall Fringe Area	rainfall_area_percent	1	4	% of pond area
Inflows	Runoff/Excess Soil Moisture	Soil Depth Scale	soil_depth_percent	0.8	2	% soil column depth
Inflows	Pond Fringe Groundwater	Inter-annual Groundwater	gw_in_percent	1	4	% direct rainfall
Inflows	Shallow Seep Groundwater	Groundwater Seep: - Watershed Scale - Threshold - Lag	 gw_seep_wshed gw_seep_thresh gw_seep_lag	 0 0 2	 0.2 3 5	 % of watershed area % mean annual precip month
Inflows	Deep Fault Groundwater	Deep Fault Flow: - Watershed Scale - Threshold - Lag	 deep_fault_flow_wshed deep_fault_flow_thresh deep_fault_flow_lag	 0 0 5	 4 4 9	 % of watershed area % mean annual precip month
Outflows	Soil Moisture/ET Groundwater	Groundwater Out ET	gw_out_et_percent	0	0.5	% ET losses
Outflows	Leaky Pond Groundwater	Groundwater Out Bottom	gw_out_bottom	0	0.5	% pond volume
Outflows	Evapotranspiration (ET)	N/A	N/A	N/A	N/A	N/A
Outflows	Spillway	N/A, fixed spillway elevation	N/A	N/A	N/A	N/A

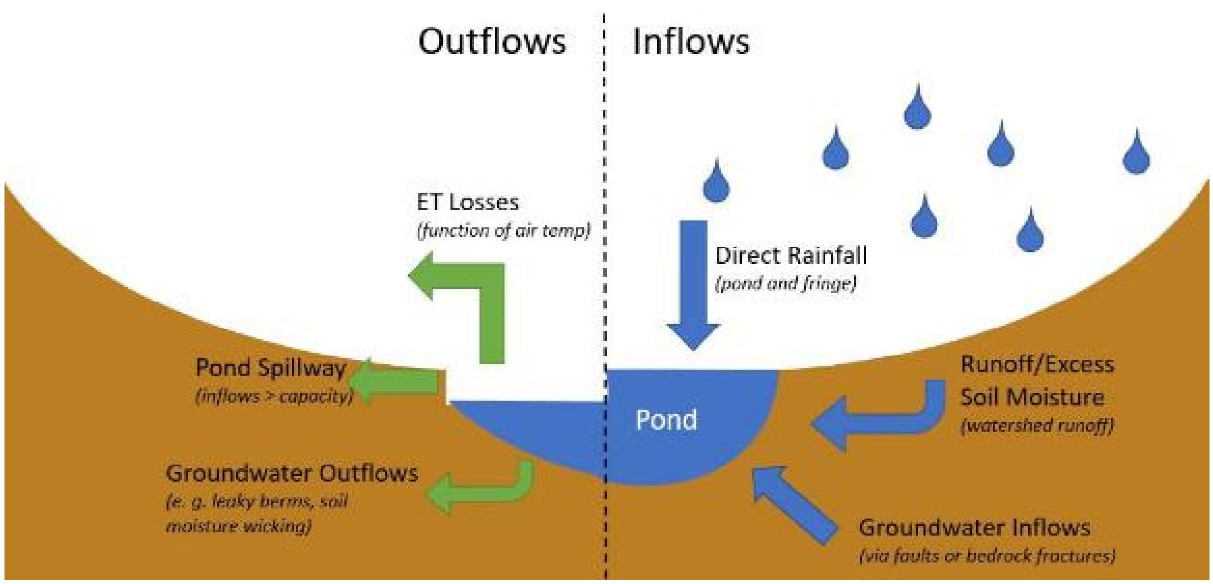


Figure 5-1 Model schematic diagram.

Model inflow modules are:

Direct Rainfall. Precipitation that falls directly on the pond surface plus an additional pond fringe area that directly contributes water to the pond. Pond fringe area was suggested to be up to 2 to 4 times (i.e. 200 to 400 percent) the pond surface area by Hecht and Napolitano (1991), who demonstrated that bank-exchange zones in surrounding hollows and swales contribute directly to runoff into the ponds once the near-pool watershed has reached watershed saturation. The area of the pond fringe is specified by the rainfall fringe area parameter and is represented as a percentage of total pond area. Fringe area depends largely on local topography and soil properties.

Runoff/Excess Soil Moisture. A soil-moisture accounting routine calculates the monthly soil moisture in the watershed. Maximum soil water capacity is calculated using soil properties of the contributing watershed. When precipitation exceeds available soil-water capacity plus ET, the excess precipitation is routed into the pond as runoff. To adjust for local variation in the ability of a soil to store water, regional soil properties can be adjusted as needed to account for local soil properties based on field observations and expertise with the model input parameter soil depth scale. The watershed size may need to be adjusted in the model refinement process to account for highly fractured watersheds.

Groundwater Inflows. Groundwater inflow delivery mechanism and timing varies widely based on soil types, underlying geology, and pond construction and so three types of groundwater inflows have been incorporated in Pond-IT. They are listed below in increasing order of lag from incident rainfall to appearance in the pond.

- **Inter-annual Groundwater Inflow**. Ponds are typically in local topographic depressions, so soil moisture from the surrounding area can infiltrate into the pond fringe area over short timescales. To model this, the direct rainfall is lagged 1 month, and scaled by the model parameter, pond fringe groundwater, represented as a percent of direct rainfall. Modeling results tended to under-predict pond water surface elevations in years following very wet years and over-predict pond water surface elevations following very dry years. To address this long-term effect of precipitation, a memory scaling factor was applied to this variable, represented by the ratio between the previous year's annual precipitation and the historical average annual precipitation. For example, after WY2014, which was very dry, the memory scaling factor would reduce the pond fringe groundwater inflow during WY2015, because the dry conditions of WY2014 over-taxed shallow aquifers, which needed to be re-filled prior to resuming contributing groundwater into a pond.

- **Shallow Seep Groundwater Inflow**. In watersheds with shallow, fractured bedrock, additional groundwater discharge can be sourced from these fractures with a medium-term time lag ranging from two to five months. Previously completed model results and calibration data have shown that this medium-term groundwater discharge is typically only active in wet years, when precipitation is above a certain shallow fracture threshold, which is specified in the model using the annual precipitation. The amount of water reaching the pond is based on the total volume of water stored in the soil column below the root zone[3]. This volume of water is released more quickly when the soil column is saturated, and more slowly when the soil is drier. The total volume of water is calculated over a shallow fracture contributing watershed area, which can sometimes be different than the contributing surface watershed area, depending on topography, deep weathering and geology and so scaled as a percent of total watershed area.

  Shallow bedrock fracture groundwater seeps are modeled so that either the seep is active and contributing water to the pond, or the seep has run dry. The threshold for when the seep is active and contributing varies by pond, with some seeps active every year and other active during only the wettest years.

  Although this groundwater inflow module was designed to address shallow bedrock fracture processes, this model can estimate any hydrologic inflow that is a function of excess soil moisture with a lag time of 2 to 5 months.

- **Deep Fault Groundwater Inflow**. Groundwater that flows through deeper bedrock fractures and faults is often slower than shallow bedrock fracture ground water flow. The total amount of deep fault groundwater inflow is the deep fault percentage of precipitation over the contributing watershed. The deep fault time lag is parameterized at seven to eight months. The lag may not represent actual groundwater flow velocities through the inferred faults, but instead may represent the timescale at which groundwater elevations in the basin have adjusted for discharge into the pond to be numerically significant. Ultimately, deep fault groundwater inflow is best monitored rather than estimated based on soil properties, as water levels beneath the pools can (a)

[3] The root zone is assumed to be 18 inches below ground surface.

also originate from delayed drainage of landslide scarps, and (b) may be largest during the second or third year of above-average rainfall.

Note that both the Deep Fault Groundwater Inflow and Shallow Seep Groundwater Inflow modules can be turned off during model prediction in both the Excel and Python model versions. This saves model computation time when these modules aren't applicable to your hydrologic system.

Model output modules are:

Evapotranspiration (ET). ET is calculated using the Blaney-Criddle Equation, represented by

$$ET_o = p\,(a\,T_{mean} + b)$$

where ET_o is the ET of the reference crop, irrigated turf, which is published by CIMIS as a function of CIMIS zones (CIMIS 1999), T_{mean} is the mean monthly temperature, and p is the mean daily percentage of annual daytime hours as a function of site latitude, and a and b are fitting parameters estimated using least squares fit to the historical mean monthly air temperature. The Blaney-Criddle Equation is a simplified method for deriving ET, only using air temperature and zonal reference ET as input parameters. Our choice to use a monthly model timestep reduces the likelihood that the more complex Penman-Monteith equation would improve model results. At a minimum, the Penman-Monteith formula requires daily timeseries data for solar radiation, wind speed, relative humidity, in addition to air temperature, which can vary significantly between pond locations and even within a single watershed. Use of the Blaney-Criddle Equation assumes that ET_o for the reference crop, is approximately equal to ET from a standing body of water (Allen et al., 1998).

Spillway. In wet months, the pond may spill, with water surface elevations exceeding the spillway elevation during these times. However, these spill events do not need to be explicitly modeled for the purposes of hydroperiod modeling and are therefore removed from the model, with water surface elevation limited to the spillway elevation.

Groundwater Outflows. Groundwater discharge varies as a function of pond soil permeability and water use on the pond fringe, so two types of groundwater outputs have been used in Pond-IT. They are:

- **Soil Moisture or ET Groundwater Outflow.** As seasonally increasing air temperatures places more demand on water supplies in the pond fringe, ponded water is lost through additional vegetation uptake or the wicking of dry soils not captured in the calculated ET from the water surface. Active grazing in the pond area may also increase this type of groundwater loss as cattle are likely to drink more water in summer months compared with cooler, wetter months. Water lost in this way is parameterized as a percent of ET to groundwater over the pond fringe area. The magnitude of this parameter sets the shape of the draw-down curve in the summer months when ET is high; the higher the percentage loss, the steeper the drawdown curve.

- **Leaky Pond Groundwater Outflow**. The soils underlying each pond have a range of soil permeability and connectivity to shallow groundwater. Clayey soils prevent water from infiltrating into the shallow subsurface as quickly as loamy or sandy soils. Except for some Pedogenic ponds, we expect most ponds to consistently loose some amount of water to the shallow subsurface, as a function of the volume of water in the pond. A fuller pond loses a larger volume of water over the larger wetted pond bottom area and with higher head pressure exerted on the underlying soils, compared with pond that is less full. Therefore, groundwater output is specified as a function of total pond volume as a percent pond volume to groundwater. Each month, the pond loses the specified volume of water to the shallow subsurface, which typically ranges from 2 to 40 percent. The higher the value, the "leakier" the pond, which may relate to the composition of the underlying soils, the proximity to faults and fractures, or the construction of the berm. The rate at which a pond loses water because it is "leaky" (i.e. the percent pond volume to groundwater is larger) defines the shape and slope of the draw-down curve.

  This model module does not allow for depth-variable leakiness – for example, some ponds have a fine clay bottom, but more permeable sides or leaky berm and so losses change as a function of inundation depth. This feature could be built in future model iterations.

5.3 Model Results and Outputs

5.3.1 Interpreting Calibrated Historical Model Results and Model Refinement

The model uses the provided calibration data to perform a least-squared error minimization function. Refining model fit will typically involve either extending or decreasing pond hydroperiod for better agreement between calibration data and the model simulation results. Because of the self-predicting nature of the model, model refinement is largely limited to the following refinement techniques:

- **Groundwater model modules:** There are two groundwater modeling modules which add a medium- and long-term groundwater Inflow function for use in seep- or spring-fed ponds. They are called **Shallow Seep Groundwater Inflow** and **Deep Fault Groundwater Inflow**. See Section 5 for more details. It is recommended that users start with these modules turned off. This has two benefits: 1) If these two groundwater functions are not needed to build a good model fit, model computation time is reduced, and 2) Excluding these two functions will highlight where you may have otherwise unknown seep processes.

- **Refine default parameter range:** The model predicts the best-fit model parameters, but within a specific range of possible answers. Once a user is familiar with the individual parameters, adjustment of the fitting bounds can be adjusted. As with any numerical solver in a non-linear optimization problem, there typically exist many local minima and therefore changing the initial guess or default start value sometimes results in a slightly different answer. It is not recommended to make the range of possible values larger, but one could reduce the range of possible values (i.e. increase min, decrease max). If using either of the two Groundwater model modules (previous bullet point), it may be especially useful to adjust the lag time by one month in either direction to adjust hydroperiod to be either wetter or drier, depending on the modeling goals.

- **Adjust/refine calibration data:** Using historical aerial imagery to collect model calibration data can be somewhat interpretive. Often pond fringe vegetation can obscure the exact wet-dry transition, or historical sedimentation in pond makes older aerial imagery not applicable to the stage-storage rating curve provided. As a result, calibration data can be refined and datapoints removed or added. Be sure to include calibration data when the pond is dry (area set to 0 or elevation set to pond bottom). Pond data (area or elevation) should not exceed the capacity of the pond at the spillway elevation.

- **Adjust/refine input data:** It may be necessary to adjust the input parameters to achieve the desired model objectives. For example, the contributing watershed calculated using topographic drainage area may not be representative of hydrologic contributions in a highly fractured environment.

- **Use Historical Design model scenario to manually adjust model fit parameters:** The model uses a numerical solver and weights all calibration data points equally. As a result, the best-fit model result may not produce the most realistic results for your system. Once an initial model is predicted using the solver algorithm, manual adjustments of model input parameters may yield more representative model results. This can only be accomplished using the Python version of the model.

The resulting best-fit model parameters can also help you understand some information about the dominant hydrologic processes, although should be used carefully and in the context of an existing site-specific set of observations and knowledge. Table 5-3 summarizes the default model parameters, and possible implication of the model parameter results.

Table 5-3 Summary of model modules, model fit parameters, and potential implications/uses.

	Model Module	Model Fit Parameter (Excel Model)	Implication
Input	Direct Rainfall	Rainfall Fringe Area	Higher value indicates larger local "bowl" shape or local soil moisture storage
	Runoff/Excess Soil Moisture	Soil Depth Scale	Higher number indicates soil data may under-represent runoff potential in the watershed
	Inter-annual Groundwater	Inter-annual Groundwater	Inter-annual groundwater inflow adjustment based on total rainfall from previous water year
	Shallow Seep Groundwater	Groundwater Seep: - Watershed Scale - Threshold - Lag	Use of this module means medium-term groundwater input, perhaps from shallow groundwater sources or young fracture water
	Deep Fault Groundwater	Deep Fault Flow: - Watershed Scale - Threshold - Lag	Use of this module means long-term groundwater input, perhaps from deeper fault/fracture flows
Output	Soil Moisture/ET Groundwater	Groundwater Out ET	Higher value indicates more ET losses due to veg/cattle/etc.
	Leaky Pond Groundwater	Groundwater Out Bottom	Higher value indicates leakier pond/berm
	Evapotranspiration (ET)	N/A	
	Spillway	N/A, fixed spillway elevation	

5.3.2 Model Output Plots and Data

The model produces the following output types.

Data. Model output data is saved in either .csv format or within the Excel workbook itself. The data also include the best-fit model parameters. More specifics about where to find output data are available in the sections for either the Excel or Python versions of the model.

Timeseries. A historical model simulation will produce a timeseries plot which begins in October 2000 and plots the model prediction through your historical model end date (Figure 5-2). The calibration data are plotted when applicable.

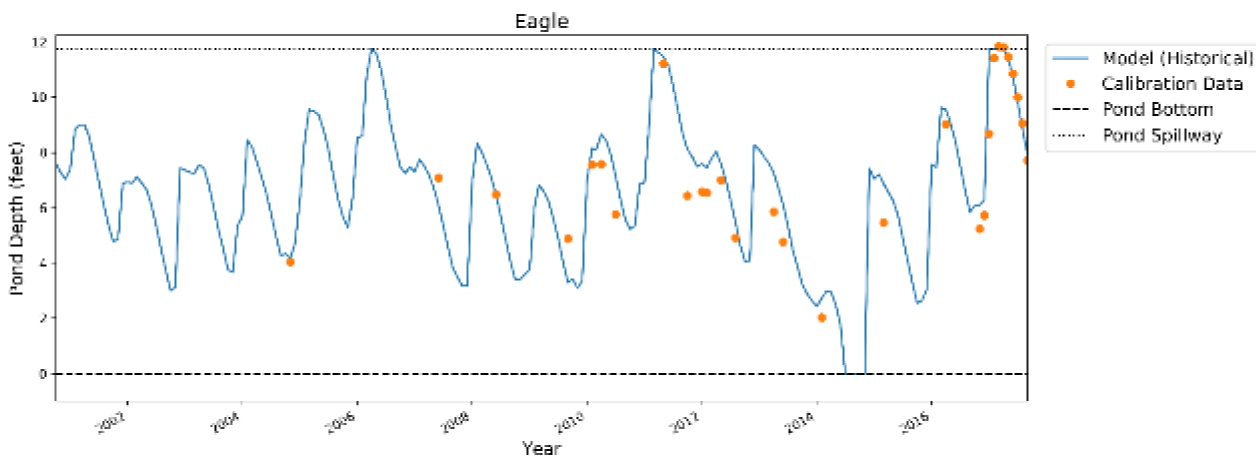


Figure 5-2 Example pond timeseries plot.

Grid Plots. A projected model will produce a hydroperiod grid plot which depicts the inundation probability for a given month and year or decade (Figure 5-3). The annual grid plot is more useful for model understanding general model hydrologic patterns and processes. However, for interpretations of climate change impacts, we recommend using the decadal grid plots which better represent the general and agreed-upon decadal shifts in climate, but don't over-analyze the climate projections for individual years which has less meaning in terms of projected inter-annual variability.

The color bar indicates the inundation probability calculated amongst the project GCMs used in the model and the years in the decade. The inundation depth threshold is specified as a model input and only changes the threshold at which the pond is considered "inundated." For example, the project objective may be to maintain a 2-foot water depth through August each year as required for the lifecycle of the target species. An inundation depth set equal to 2 feet would produce grid plots with the probability of inundation great than 2 feet. An inundation depth set equal to 0 feet would calculate the probability of inundation of any amount.

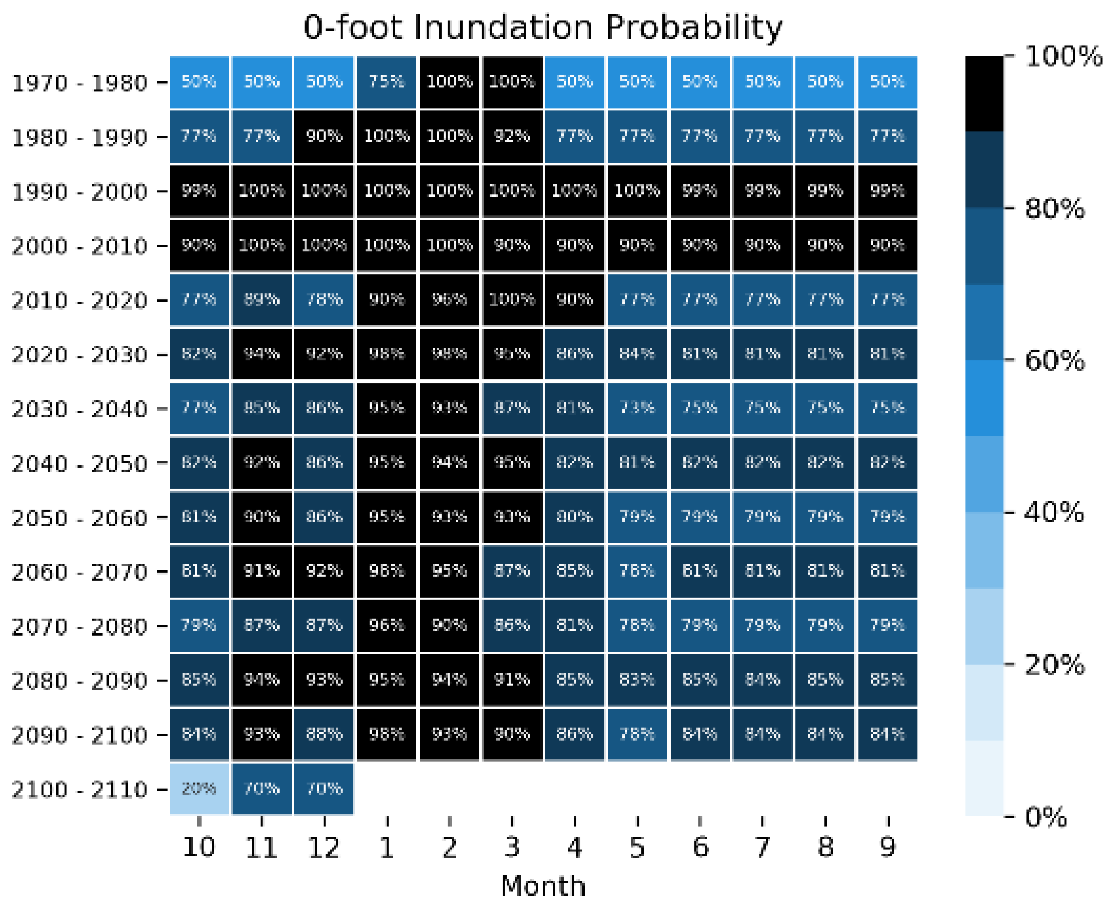


Figure 5-3 Example decade grid plot.

5.4 Design Scenarios

A primary feature of the Pond-IT model is to aid the user in building and simulating "what if" scenarios for design alternative hydroperiod optimization. Generally, a pond is either too wet and the goal is hydroperiod reduction, or the pond is too dry and the goal is hydroperiod extension. The range of feasible design alternatives will vary greatly depending on the physical and hydrologic constraints of the site, but in the next two sections, we've outlined some potential design alternatives and ways to explicitly model the alternatives.

Generally, the primary goal of decreasing hydroperiod of a pond is for invasive species control, specifically bull frog management which require water that is perennially wetted to complete their breeding lifecycle. Conversely, extension of hydroperiod may be desired for ponds which could better support a target species with enhancements. A few potential strategies for changing pond hydroperiod are:

1. **Changing Pond Capacity:** A reduction in pond capacity may allow the pond to naturally dry up by the target month in the short-term. However, adaptive measures are often needed to maintain optimal hydroperiod in future years as projected climate data suggests a general warming trend in much of California in the coming decades. In cases when available water supply is not retained in the pond, increasing pond capacity may also increase pond hydroperiod. This may be particularly effective for ponds that had optimal hydroperiod prior to sedimentation. To model a change in pond capacity, alter the stage-storage relationship to reflect new grading, or adjust the spillway elevation which will change the maximum pond capacity by the corresponding amount.

2. **Altering Pond Surface Area:** In ponds where ET dominates the timing of pond drying, changes in the overall pond shape may have a significant effect on the pond hydroperiod. For example, a wide shallow pond may dry up quicker than a deeper pond with a smaller surface area. This may be an especially useful scenario when small modifications to the hydroperiod are desired, but the total volume of water stored is not easily changed (i.e. pond does not routinely spill or cannot be easily released downstream). To model a change in the pond surface area, alter the stage-storage relationship.

3. **Target Inundation Depth:** When a specific inundation depth is desired for a target species habitat benefit, a deeper or shallower pool can be simulated using a revised stage-storage relationship.

4. **Redirect Overland Flow:** In some select circumstances, modifications to existing roadways or trails may be able to decrease or increase the contributing watershed size. This is modeled by changing the watershed area.

5. **Adaptive Drain:** Given the anticipated warming trend throughout much of California, drain infrastructure can be installed to be able to adaptively drain the pond, either completely, or to a target depth to allow for natural and gradual late-season drying processes. Deciding to drain a pond completely at the end of the season does not require a Pond-IT model and will likely be an operational question. The Pond-IT model could simulate the partial draining and subsequent

natural drying of ponds and aid in the selection of drain depth and drain date, however that feature is not included in this build of the Pond-IT model. Please contact us for more information.

6. **Clay Liner or Berm Repair:** In some cases, the pond hydroperiod is reduced because of a leaky berm or highly permeable or leaky pond bottom. In practice when a pond is leakier than desired, it is common to line a pond with a clay material, or to replace the sediments in a berm with less permeable or more compact materials. In theory this can be simulated using Pond-IT by reducing the model parameter for **Leaky Pond Groundwater Outflow**, however it is difficult to predict with any certainty how a clay liner or berm repair will affect the pond leakiness and is therefore challenging to assign a numeric value to the reduction in leakiness. However, the Pond-IT model can be used to simulate a range of possible scenarios, or a sensitivity analysis if desired. For example, it may be useful to simulate the resulting pond hydroperiod if the pond leakiness were reduced by a specific amount.

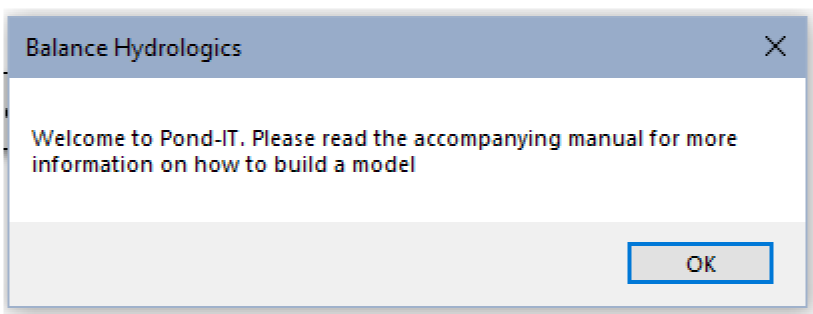
6 RUNNING THE POND-IT EXCEL MODEL

6.1 Installation and Initial Set-Up

Download the Microsoft Excel version of the Pond-IT model here: http://balancehydro.com/pond-inundation-and-timing-model-pond-it/. To get the model set up the first time, you must first install both the Pond-IT and solver add-ins.

Double click on Pond-IT model file to open in excel (Pond-IT_Model_v1.0.xlsm). If prompted click **Enable Content**.

Greeting window should pop up → press **OK**.



You are now viewing the **Instructions tab**. Please review the workflow by clicking on each text bubble. For detailed guidelines for preparing input data review Section 5.1 of this guidebook.

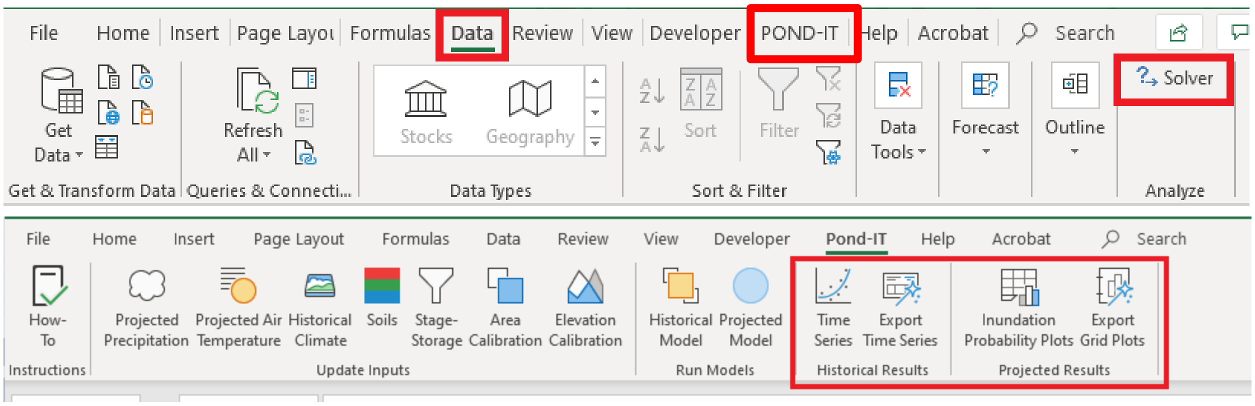
6.1.1 Load Solver and Pond-IT Add-ins

Load **Solver** Add-in: File → Options → Click on **Add-ins** on the left-hand table of contents → In the **Add-Ins available** box, select the check box next to the Solver add-in →click **OK**.

If you don't see Solver in the available box then, run setup program for Excel → choose **Change** option to install Add-in. Restart Excel and Solver should appear in the Add-ins available box.

Load **Pond-IT** Add-in: **File**→ **Options** → Click on **Add-ins** on the left-hand table of contents → In Add-In dialog box click **Browse** to locate add-in → click **OK**. The Pond-IT Add-in should be in the Add-in subfolder in the zip folder downloaded with the model spreadsheet.

Now you should see Solver in the Data ribbon and Pond-It as its own ribbon at the top bar of Excel.



6.2 Preparing Excel Model Inputs

6.2.1 Define Initial Conditions

Review **Initial Conditions** tab and define model inputs and model fit parameters.

	Initial Condition Variables				Units
Model Inputs	Latitude	37.31			
	ETo Zone	8			
	Spillway Elevation	11.74			ft
	Watershed Areas	504000.00			sq ft
	Inundation Depth	0.00			ft
		Initial Guess (Model Uses Solver)	Set Model Params (Model Does Not Use Solver)	Current Model Params	
	Use Solver?	y			
Model Fit Parameters	Groundwater Out ET	0.050	0.050	0.00000	% ET losses
	Groundwater Out Bottom	0.050	0.050	0.08957	% pond volume
	Rainfall Fringe Area	1.000	1.999	1.00187	% of pond area
	Soil Depth Scale	2.000	1.501	0.80000	% soil column depth
	Pond Fridge Groundwater Input	0.300	0.100	1.80320	% pond volume
	Deep Fault Flow Watershed Scale	0.000	0.000	0.00000	% of watershed area
	Deep Fault Flow Watershed Threshold	1.000	0.000	1.00000	% mean annual precip
	Deep Fault Flow Lag	6	2	6.00000	month
	Groundwater Seep Watershed Scale	2.000	0.000	2.00000	% of watershed area
	Groundwater Seep Threshold	1.000	0.000	1.00000	% mean annual precip
	Groundwater Seep Lag	3	5	4.00000	month
ET Initial	Blaney Criddle Initial Fit Value, a	0.50	1.03	0.50	
	Blaney Criddle Initial Fit Value, b	8.00	-0.21	8.00	

RESET:
Initial Condition Variables

Mode inputs are entered for each pond and remain fixed throughout the model simulation optimization.

Model fit parameters are entered in either column D or column E (see Section 5.1 for more information). Column D specifies the initial guess model fit parameters. The macro button at the bottom of the screen will reset Column D to the default values. The numerical solver will then predict the best-fit model parameters which minimizes the least squared error between the calibration data and predicted pond elevation. Model prediction is enabled when cell D9 equals "y" (without quotes, lower case) and the cell turns green. Best-fit model parameters will be updated in Column E after the model runs successfully.

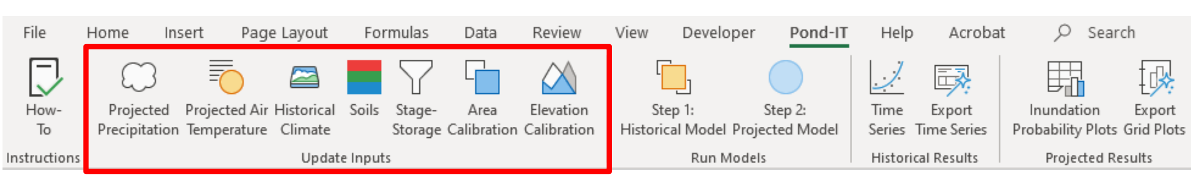
In Column E you can manually input choices for each of the model fit parameters and Pond-IT will use those values, rather than fit to the calibration data. This is most useful after first finding the best-fit model parameters (enable Column D and run) and then tweak numbers representative of various design or pond alteration scenarios. To enable values entered in Column E, change cell D9 to "n" (without quotes, the cell will turn red).

To turn off the Deep Fault and Groundwater Seep model modules, set the scale parameters (rows 15 and 18) equal to zero. We recommend the first model simulations completed with these modules disabled and added in if calibration data suggests that the hydroperiod should be longer.

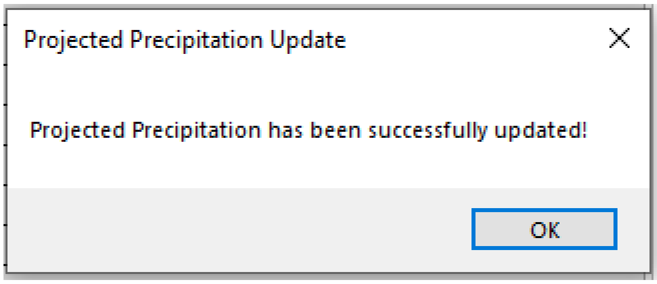
After completion of a successful historical model run (with or without solver), the model parameters used will be reported in column F. These will be used in the projected model when run.

6.2.2 Load Input Data

To load the other input datasets, navigate to the Pond-IT ribbon at the top bar of Excel. Begin by updating the seven input files. Follow the prompts after clicking each of the input icons: projected precipitation, projected air temperature, historical climate, soils, stage-storage relationship, area calibration and elevation calibration.

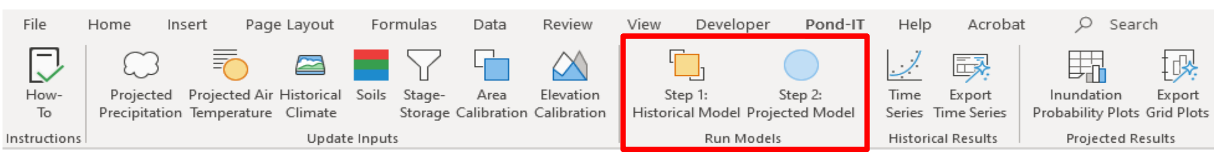


Navigate to the folder your input files are in → select the appropriate file → press **Open.** Once input is loaded from file, you should receive a prompt of the successful update → press **OK**.

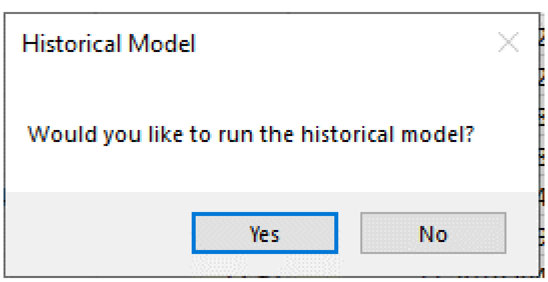


6.3 Running the Excel Model

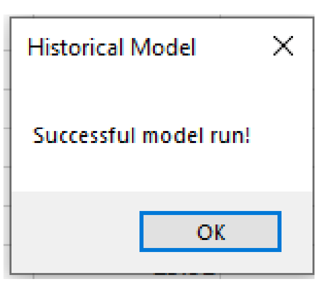
Once your input variables have been updated to the spreadsheet, you are ready to run your historical and projected models.



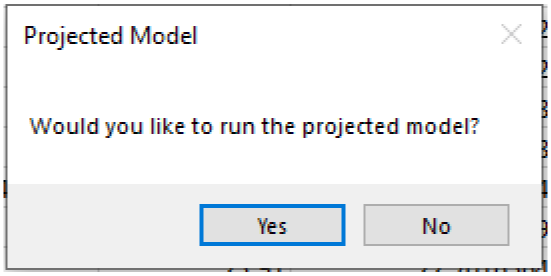
Click Historical Model → acknowledge prompt → click **Yes**.



This process may take a couple of minutes giving you a blue circle as the mouse as it calculates in the background. You should be prompted when the model is complete.



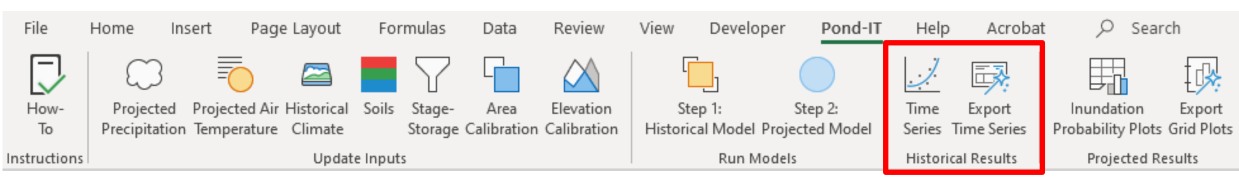
To run a projected model, click Projected Model → acknowledge prompts → click **Yes.** You should also be prompted when the model is complete.



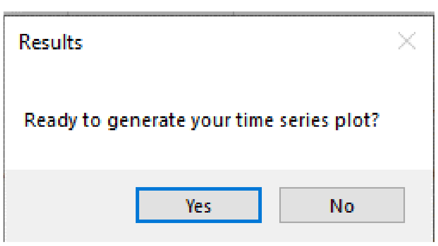
6.4 Excel Model Results

6.4.1 Historical Model Results Graphics – Timeseries Plot

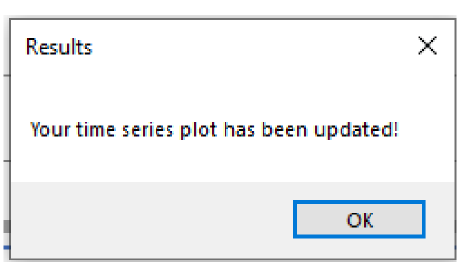
You are now ready to produce some graphics. Start with your historical model results so that you can review the historical model against your calibration data.



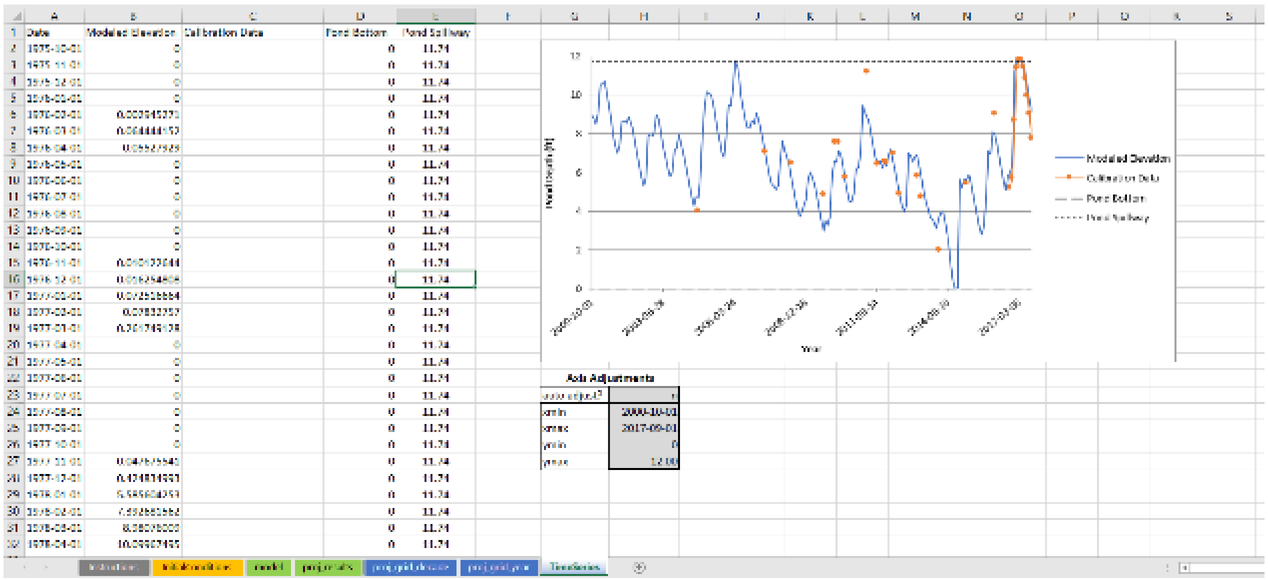
Click **Time Series** icon → acknowledge prompts → click Yes.



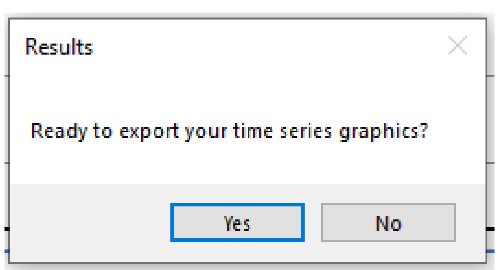
You should be prompted when time series has been updated. Press **OK**.



Review graphic located on **TimeSeries** tab. You can manually adjust your plot axes using the editable cells below the plot (grey cells). Changing cell H23 from 'n' to 'y' (without quotes) will use default axes values based on the data.



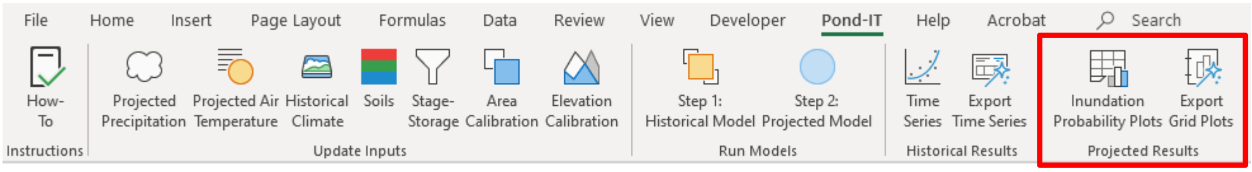
After you review the historical model, if you need to update initial conditions or input data do that now and rerun both models. If you are satisfied with your historical mode you can export a .jpg of the timeseries plot. Click **Export Time Series** → acknowledge prompt → click **Yes**.



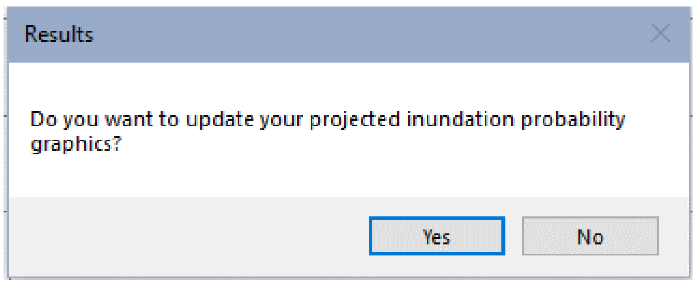
A **Select a Folder** window will pop up. Navigate to folder you want your graphic to save in → click **OK.**

6.4.2 Projected Model Results Graphics – Grid Plots

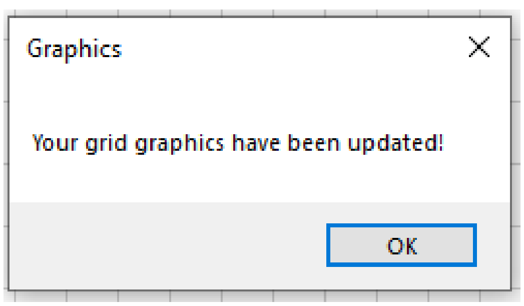
Once the projected model is complete, you can generate grid probability inundation plots for each simulated year and decade. See Section 5.3.2 for more information. In the Pond-It ribbon → **Projected Results → Inundation Probability Plots.**



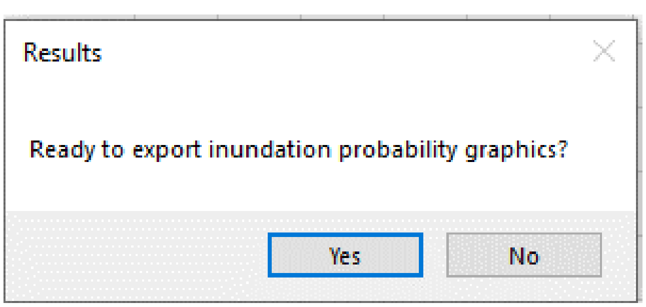
Acknowledge prompt → click **Yes**



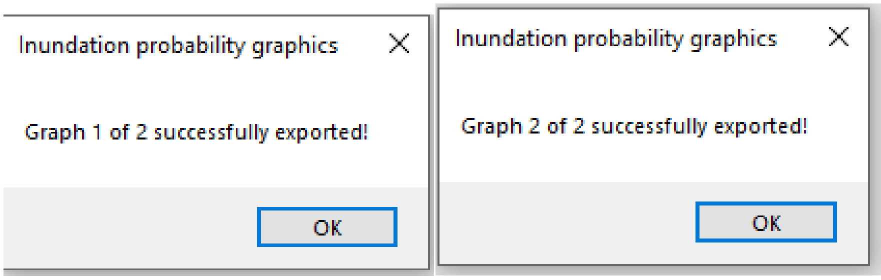
This process may take a couple of minutes giving you a blue circle as the mouse as it calculates in the background. You will be prompted when the inundation probability graphics are complete.



Review **Proj_grid_decade** and **Proj_grid_year** tabs. When you are satisfied with your projected model graphics you can export both figures as .jpg files. Navigate to the Pond-It ribbon → Projected Results → **Export Graphics** → acknowledge prompt → click **Yes**.



A **Select a Folder** window will pop up. Navigate to **folder** you want your graphic to save in → click **OK.** You will be prompted when your graphics have been successfully exported.



6.5 Debugging Pond-IT Excel Model

The following is a list of possible error messages or issues that may arise when using the Excel version of the Pond-IT model, with a set of possible steps to find a resolution. Many model errors are a by-product of model input data which does not follow the required format. Please review Sections 5.1 and 6.2 for more details on preparing the input data.

6.5.1 VBA Runtime Error

If you encounter a VBA runtime error, try saving, closing, and re-opening your Excel workbook.

6.5.2 Model Produces #N/A

Double check your input data. Either you can reload each data type, or you can unhide the input tabs by right-clicking on the sheets (Soils, Historical Climate, Projected_Precip, Projected_AirTemp, etc.) to verify the data is consistent with the input file examples. In particular, make sure the stage-storage data includes the full range of area and depth/elevation.

7 RUNNING THE POND-IT PYTHON MODEL

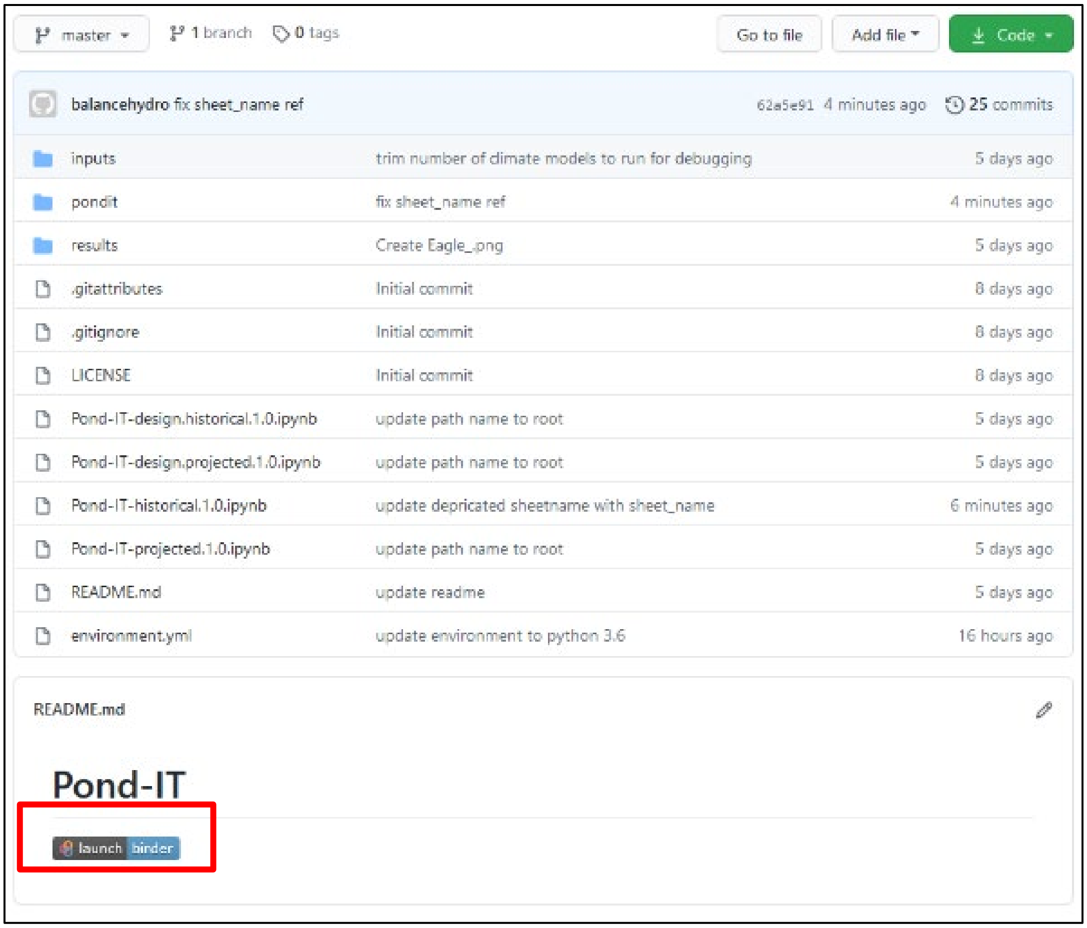
The Python version of the Pond-IT model can be found at https://github.com/balancehydro/Pond-IT. The Python repository has been set up so you can run and install Python on your own computer, or alternatively run the model on an open-source and publicly available platform called Binder. If you intend to run the model for multiple sites or intend to iterate a model over a long time period (more than a week or so) then we recommend you install a local Python environment and run the model on your local machine. The Binder notebook feature is ideal if you want to test out the Python version of the model.

7.1 Running Pond-IT with Binder

To set up a one-time virtual machine you can use the open-source python virtual environment called Binder. To launch an instance of the Pond-IT repository, click the "Launch Binder" button. This will launch a remotely hosted version of Jupyter Notebook in your web browser which will include the necessary Python modules and dependencies and allow you to compute the Pond-IT model using remote resources (i.e. not running on your local computer). There are several limitations associated with using Binder to run the Pond-IT model:

- The Binder virtual environment will automatically shut down after approximately 12 hours, and after approximately 10 minutes of inactivity. Leaving the tab open in your web browser is considered "activity."
- Model results (data, figures, etc.) will need to be explicitly exported and saved to your computer prior to the Binder environment shutting down. If it is not saved, the data will be lost.
- Computation times may be limited by general Binder traffic and therefore unreliable; you may get faster results if run on your computer.

With these limitations in mind, running the Pond-IT model using Binder is still a great way to test out the Python version of the Pond-IT model without installing Python on your computer.



7.2 Setting Up a Local Python Environment

If you are intending to build and maintain several pond models, or are refining a model over several iterations, we recommend setting up a local Python environment on your computer. Fortunately, this can be accomplished by using the open-source Python and Jupyter Notebook distribution called Anaconda. This python environment can be installed and used specifically when running the Pond-IT model and will not interfere with any Python environment you may already have on your computer.

To install a local python environment, follow these steps:

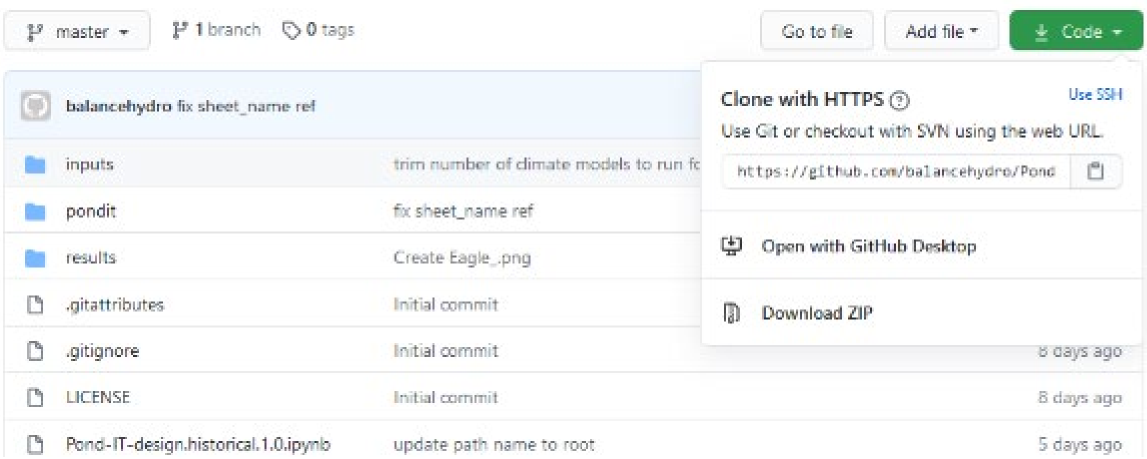
1. Unless already installed on your computer, install Anaconda from: https://www.anaconda.com/products/individual. If you have an old version of Anaconda, you may need to update. We recommend using Anaconda 4.7.0 or newer.

2. Create a folder on your computer called "Pond-IT" where your model will be stored.

3. Copy the entirety of the Pond-IT model repository to this folder. This can be accomplished two ways:

    a. Fork and clone the repository to maintain a connection to GitHub; requires a GitHub account

    b. Download the code via a .zip file; Click the green "Code" button and then "Download ZIP." Unzip the file and place the contents in your Pond-IT folder so that the file environment.yml is in the Pond-IT folder.



4. Open a terminal window. On a Mac this program is called "Terminal," on Windows it is called "Anaconda Command Prompt".

5. Change directories in the terminal window to the newly copied repository (e.g. cd Pond-IT).

6. Once you are in the Pond-IT directory, you can create your Python environment by running the command: `conda env create -f environment.yml`

    a. After initial set up you can change your Python environment to the Pond-IT environment by using: `activate pond-it`

    b. To view a list of all conda environments available on your machine run: `conda info -envs`

7. Launch your newly created python environment by using the following command from the Pond-IT directory after activating the Pond-IT environment (step 6a above): `jupyter notebook`

8. To close the instance of Jupyter Notebook, type CTRL + C twice in the terminal window. To restart, re-enter the command in step 7.

Note: To run the local Python instance, terminal must remain open on your computer. Closing terminal will kill all Python processes running on your machine and Jupyter Notebook will no longer function properly.

7.3 Running the Python Pond-IT Model Using Jupyter Notebook

After following the above steps (either Section 7.1or 7.2) to set up your Python environment, a Jupyter Notebook should launch in your default web browser. The general steps for running a python Pond-IT model include preparing the input files and parameterizing and running the model scenarios.

7.3.1 Preparing Python Model Inputs

To build a python version of the Pond-IT model, update all the input files in the "inputs" folder. The exact format of the input files must be maintained so it may be easiest to modify the existing example files. The input files required are as follows (see Section 5.1 for more details):

- Stage-Storage: one worksheet (.xlsx format) for each pond bathymetry scenario modeled (i.e. different ponds, design scenarios)

- Soils: one worksheet (.xlsx format) for each modeled watershed
- Calibration data: either as pond area (pond_area_calib) or pond elevation data (pond_elev_calib); one sheet per pond (.xlsx format)
- Historical climate data (in the hist_climate folder. Files must be in the .csv format with three columns: date, precip_in (precipitation in inches per month), temp_mean_C (average monthly air temperature in degrees Celsius). These are the three columns included in the PRISM monthly data export.

	A	B	C	D
1	date	precip_in	temp_mean_C	
2	1975-10-01	2.52	14.83333	
3	1975-11-01	0.63	10.88889	
4	1975-12-01	0.38	9.722222	
5	1976-01-01	0.24	9.555556	
6	1976-02-01	1.19	9.333333	
7	1976-03-01	2.21	9.555556	
8	1976-04-01	1.34	9.722222	

- Projected climate data in the proj_climate folder (in .csv format). Projected data for each relevant modeled location should include two spreadsheets, one for projected precipitation in inches per month and one for projected average monthly air temperature in degrees Celsius. Column names in projected climate files should be the year, month, date column and one column for each climate model used (e.g. canesm2.1.rcp85, miroc5.1.rcp85). Only required for running a climate change projection model.

	A	B	C	D	E	F
1	year	month	date	access1-0.1.rcp85	access1-3.1.rcp85	bcc-csm1-1.1.rcp85
2	1975	10	1975-10-01	1.708661417	0.721299213	2.800984252
3	1975	11	1975-11-01	1.344094488	2.372834646	9.187795276
4	1975	12	1975-12-01	7.832992126	3.447834646	4.462047244
5	1976	1	1976-01-01	12.71	1.519488189	6.898110236
6	1976	2	1976-02-01	8.151968504	2.302874016	0.026259843
7	1976	3	1976-03-01	5.086929134	6.314724409	0.412519685
8	1976	4	1976-04-01	1.037007874	0.472440945	0.929527559
9	1976	5	1976-05-01	0.040275591	0.096417323	2.355511811
10	1976	6	1976-06-01	0.394488189	0.079133858	1.101968504

- The number of climate models included in the projected model can be specified in the input file climate_models.txt. The GCMs to be modeled should be listed in this file, one on each line, if they are to be included in the projected models. When building the model, it may be advisable to start with a smaller set of GCMs for model iteration. Use of the climate_model.txt file allows all available GCMs to be downloaded, but fewer models run where appropriate. Only required for running a climate change projection model.

7.3.2 Model Parameterization and Running the Python Model

The models run with the Python code are controlled via one of three files (must be a .csv):

- main_inputs.csv
- main_inputs_design_hist.csv
- main_inputs_design_proj.csv

Each row in each file represents a unique model run. The column names in this main input file are listed in the table below with a description of the required input.

Column Name	Description
site	Unique site or model scenario name
status	"run" or "done" If set to "done", model will not run. Useful for running a subset of the parameterized models.
plot_inundation	Number indicating target depth for pond inundation (i.e. 0, 2) in feet
latitude	Latitude of the pond site, in decimal format, used to calculate ET
eto_zone	CIMIS ETo zone, see Appendix A
spillway_elev	Elevation or depth of the spillway, should be in same datum of the stage storage data
wshed_area_sqft	Contributing watershed area in square feet
soils_sheetname	The worksheet name of the input data relevant for this model run; can be useful for running several iterations or designs
stage_storage_sheetname	
calib_area_sheetname	
calib_elev_sheetname	
stage_storage_filename	Filename of the various input data types (stage storage, calibration, soils, projected and historical climate data), without file extension (i.e. excluding .xlsx)
calib_area_filename	
calib_elev_filename	
soils_filename	
hist_data_filename	
proj_precip_filename	
proj_temp_filename	

gw_seep	Whether to include the "Groundwater Seep" or "Groundwater Fault" modules in the model; should be a "y" or "n" (no quotation marks included)
gw_fault	
gw_out_et_percent	Model fit parameters. Results of the historical model run and can be copied from the output model parameter sheets and modified as needed. (Only used for design models, 3 and 4)
gw_out_bottom	
rainfall_area_percent	
soil_depth_percent	
gw_in_percent	
deep_fault_flow_scale	
deep_fault_flow_thresh	
deep_fault_flow_lag	
deep_gw_wshed	
deep_gw_thresh	
gw_seep_lag	

There are four types of Pond-IT models you can run:

1. Historical Model: Based on most representative conditions (soils, stage-storage, etc.) associated with your calibration data, run against historical climate conditions. Model predicts the best-fit model parameters (Table 5-2) for the given calibration data.

2. Projected Model: Uses the best-fit model parameters from the historical model to simulate future climate change response. Uses the same input file as the historical model (i.e. main_inputs.csv in the repository). Requires the historical model be complete and the file with the suffix "_model_params_hist.csv" to be in the "results\data\" folder for the given model scenario.

3. Historical Design: Allows the user to run several different model scenarios testing the hydroperiod response (see below). The calibrated historical model (number 1 above) must be completed prior to running this model. Uses historical climate data. Model parameters from the historical model should be copied to the main_inputs file and can be altered for a design scenario as desired.

4. Projected Design: Same as the Historical Design scenario but uses both the historical and projected climate data.

Figure 7-1 illustrates the general workflow of building all four types of models for a given pond. The first step is to build a historical model using the calibration data to derive the best-fit model parameters which are used as inputs to subsequent model builds. The process of fine-tuning the historical model is discussed in more detail in Section 5.3.1.

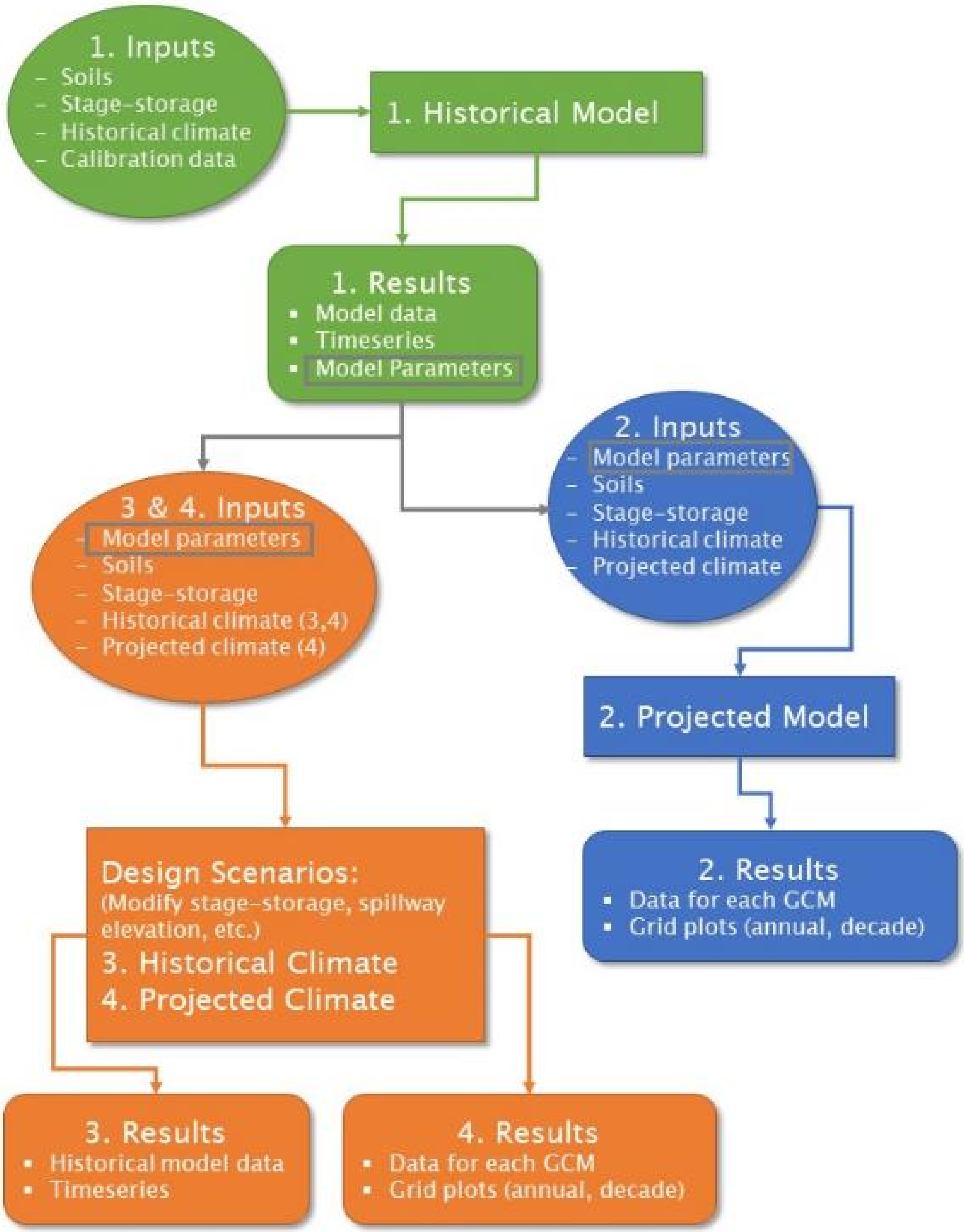
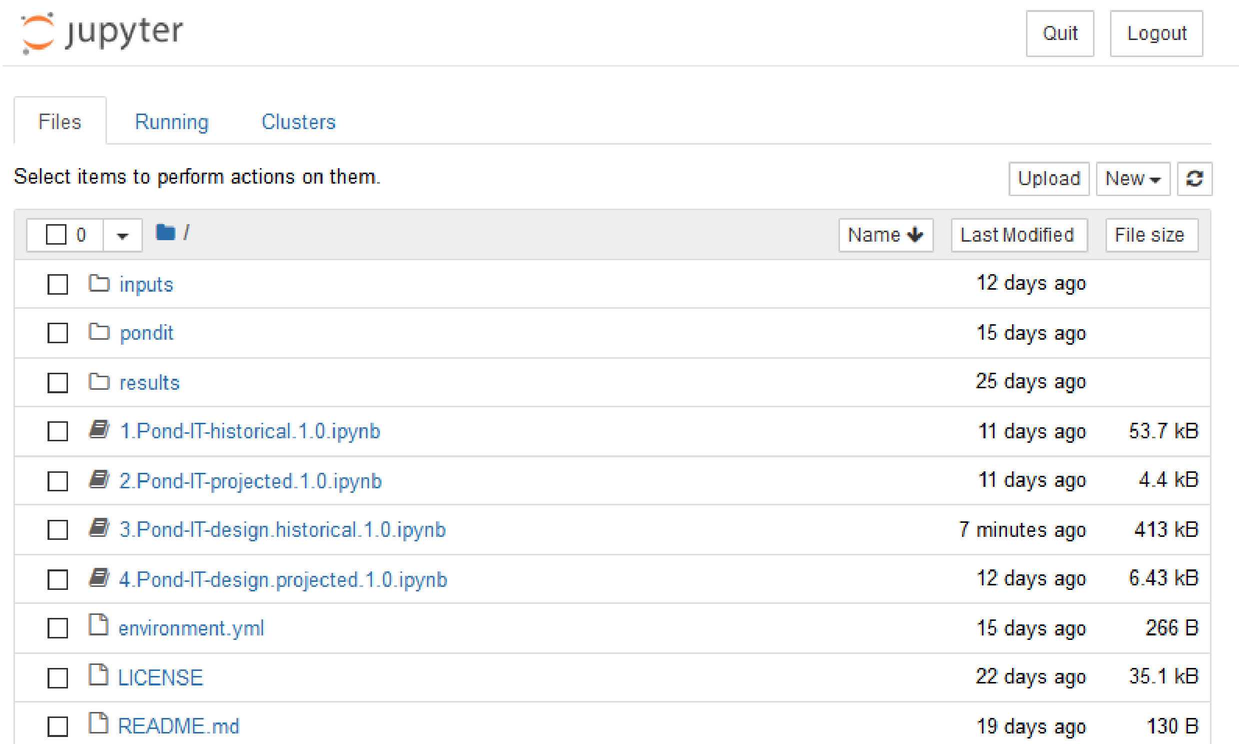


Figure 7-1 General workflow of Python Pond-IT model types.

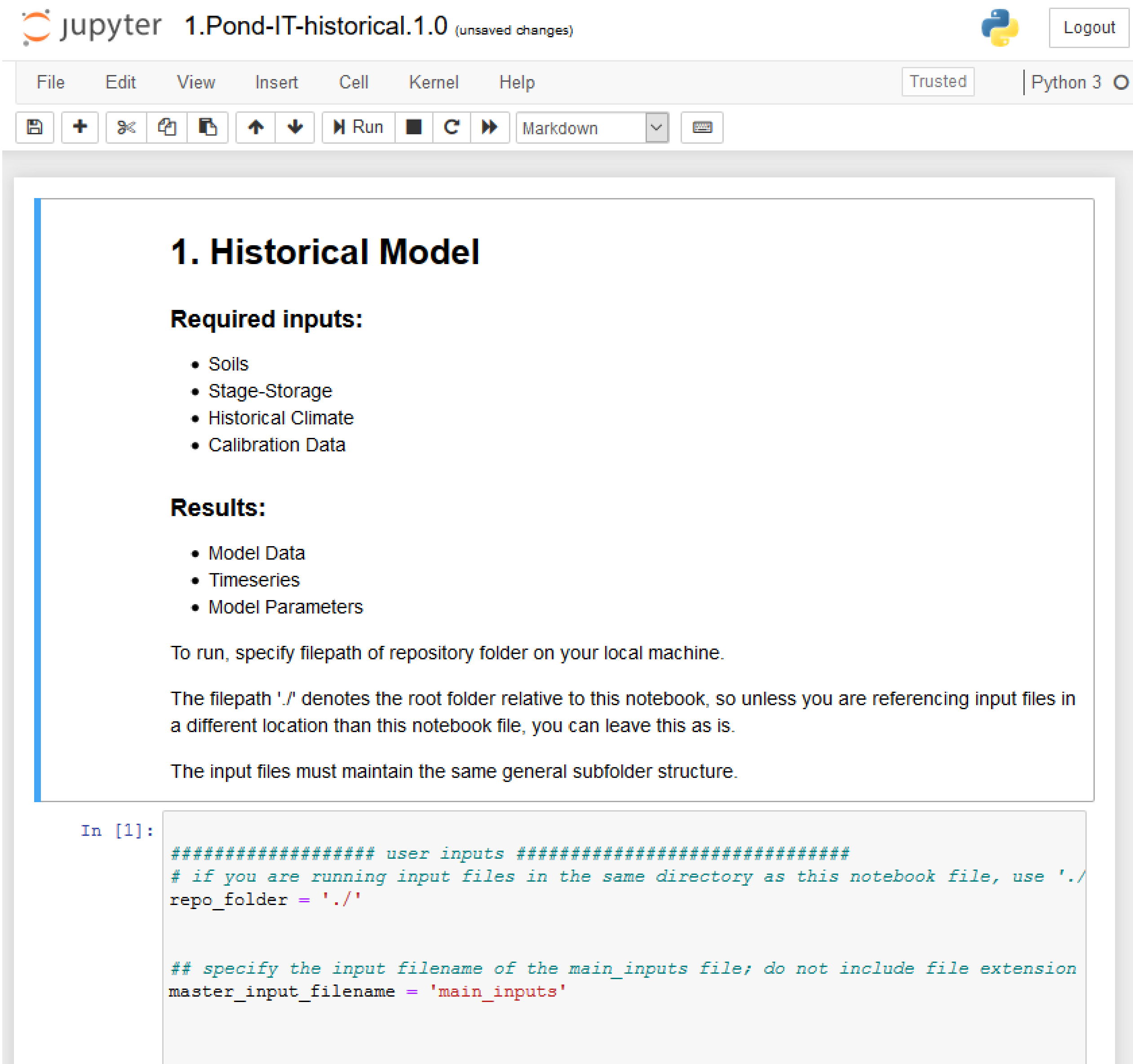
After preparation of the input files, and main_input files, you can run the model. You will find four notebook files in the Jupyter Notebook home screen:



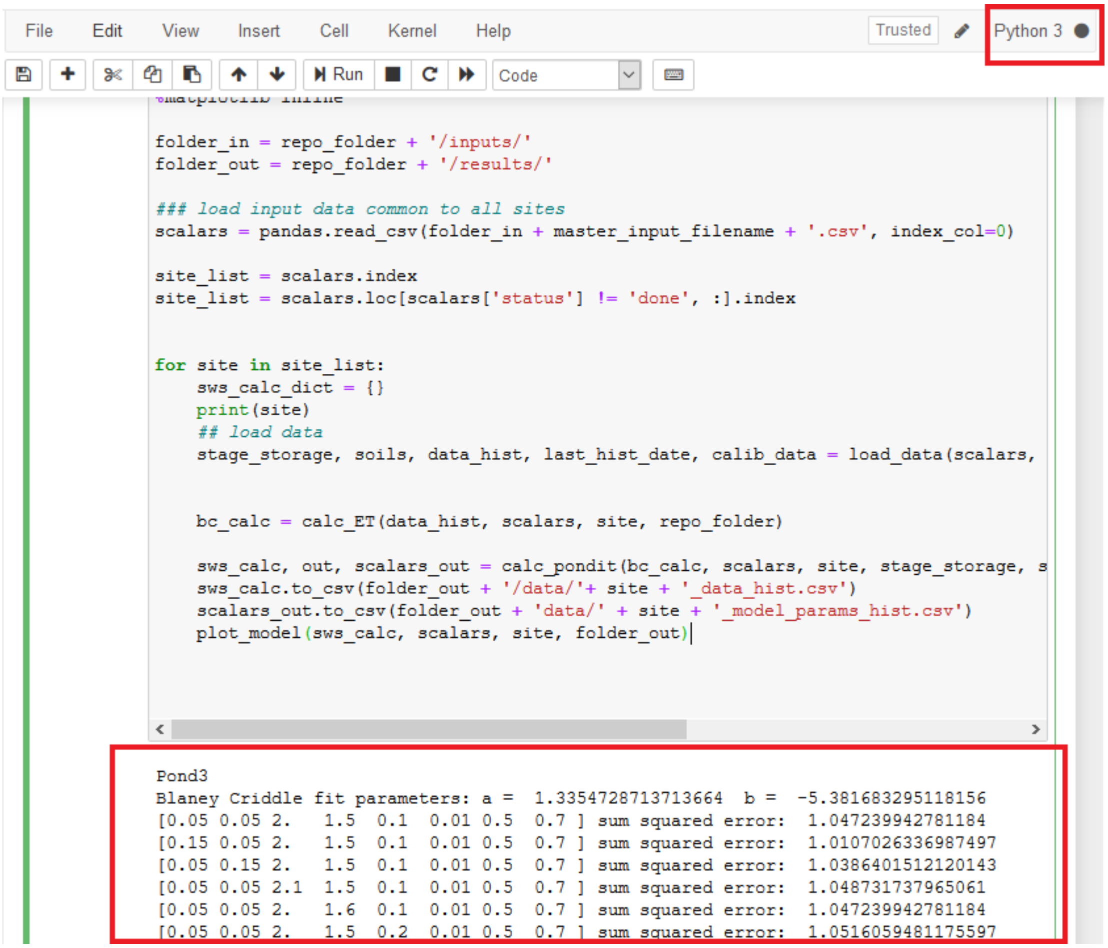
The notebooks which run each of the model types are numbered 1 through 4 and are ".ipynb" files. Click on each one to open the model code in a new tab. General instruction can be found at the top of each page. The user inputs will be clearly marked at the top of each code cell. In most cases, there is one input to specify in the notebook file:

- master_input_filename: Should equal the filename of the main_inputs file for your model run. Can be any filename; do not include the file extension.

After specifying inputs, you can run the model by clicking into the code cell and clicking run at the top or go to Cell and then click Run Cells:



The model is running if the status circle at the top right is filled in and if you see printed data below the code cell:



7.4 Python Model Results

There are four types of output files that are produced when you run the Pond-IT Python model, all of which are saved in the results folder (either in your local Python environment or within Binder. It is crucially important to export your results (and inputs) from Binder if you want to preserve them after the Python instance memory is reset. See Section 7.1 for more information. Each result type can be found in its own subfolder, as described in the following subsections.

7.4.1 Python Results: Data

For each successfully completed model, you will find a number of outputs in the data folder. Each data file will begin with the model site name specified in the main inputs folder. Data with the same site name will be overwritten. Each of the model types produce the data output files in Table 7-1.

Table 7-1 Summary of Python Model Types

Model Type	Data Output Suffix	Description
1. Historical	_data_hist.csv	Historical timeseries model computation data
	_model_params_hist.csv	Model best-fit parameter results; used as an input to Model 2 (Projected) as is and in the results folder or to be copied/modified for Models 3 or 4.
2. Projected	_proj_data.csv	Historical and projected model computation data; one file for each projected dataset used.
3. Historical Design	_data_design_hist.csv	Historical timeseries model computation data
4. Projected Design	_proj_data.csv	Historical and projected model computation data; one file for each projected dataset used. If using the same site name as Model 2 (Projected) data will be overwritten.

7.4.2 Python Results: Timeseries

Model types 1 and 3 (Historical and Historical Design) will both produce a timeseries plot in the timeseries subfolder with the site name as the file prefix. These plots are automatically created as part of the code that runs Models 1 and 3, and requires the model results data to be in the data subfolder.

7.4.3 Python Results: Grid Plots

Projected inundation grid plots are produced both annually and by decade in the corresponding subfolder with the site name as the file prefix. These plots are automatically created as part of the code that runs Models 2 and 3, and requires the model results data to be in the data subfolder.

7.5 Debugging Pond-IT Python Model

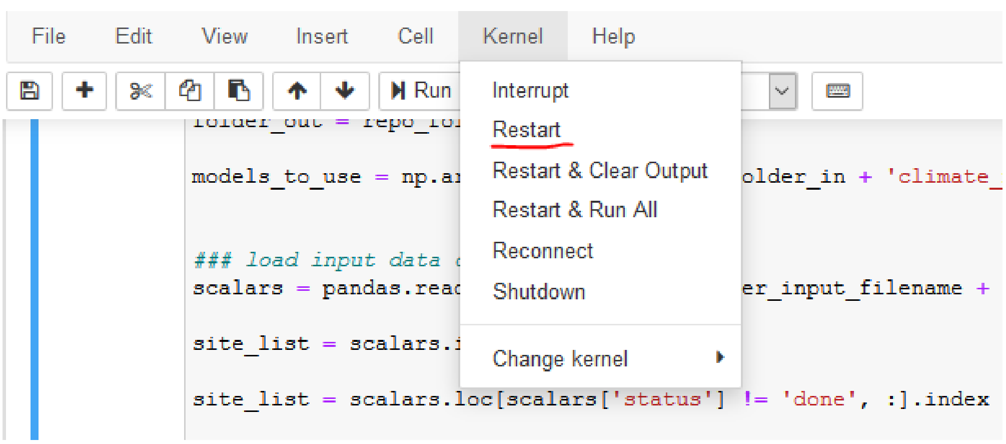
See Section 5.3.1 for more information on model results refinement. Any errors that are produced by running the Python model will be printed in the Jupyter Notebook window. A description of the most common errors follows. Many model errors are a by-product of model input data which does not follow the require format. Please review Sections 5.1 and 7.3 for more details on preparing the input data.

7.5.1 File Not Found

This error will be produced when the file path cannot be found. This can happen if you did not specify the correct filename in the main_inputs file, or input files are in a location that does not follow the established folder hierarchy. The error message will be printed with the file path that doesn't exist. Verify the spelling and file directory structure and try again.

7.5.2 Non-responsive Python Window

After some period of time Binder will time out, or your local Python kernel could stall. This can either be fixed by either a) restarting the kernel in the notebook, or restarting your instance of Python (Binder or locally, see Sections 7.1 and 7.2).



7.5.3 Value Error

If you get the error message "ValueError: operands could not be broadcast together with shapes…" then check to make sure your calibration data is not entered for any months past the end of your historical climate data.

7.5.4 Historical Model Produces Null Result

If the model timeseries plot is blank except for the calibration data, make sure all of the elevation data is internally consistent for a particular pond. For example, the calibration data and spillway are included in the range of values represented in the stage-storage relationship.

8 INTERPRETING POND-IT MODEL RESULTS USING THE GENETIC CLASSIFICATION

8.1 Genetic Classification Types

While parameters such as watershed size, pond capacity, and climate may account for many of the similarities and differences between the hydrologic responses of different ponds, other pond and watershed characteristics such as geology, soils, and topography may inform hydrologic responses and groundwater patterns. During model development, ponds were classified into one of five genetic classification types, (adapted from Bauder et al., 2009). Not all of these classifications may be present in all areas, and we acknowledge that more genetic classifications may exist.

In urban, suburban and agricultural or formerly agricultural areas, most ponds would not exist without anthropogenic intervention, which typically involved construction, stabilization, or supplementation of pond berms or spillways. The genetic classification presented here is not used to classify the processes of pond construction. Instead, the classification is focused on the geologic, geomorphic, and soil processes that would either create a topographic low in an existing drainage channel, a seep or spring, or a combination of both, and where conditions would be favorable for construction or enhancement of a pond feature. The classification is meant to aid users in evaluating potential factors with may affect model parameter calibration.

Within a classification, we have observed considerable hydroperiod variability, depending on watershed size or pond construction. For example, two ponds may be landslide dammed, but one pond dries often while the other may be inundated year-round in all but the driest years, due to larger watershed size and appropriate pond capacity to maintain ponded water. We surmise that, while foundationally important, genetic typing must be considered along with watershed size, berm construction, and groundwater inflows and outflows.

The following is a discussion of type of genetic classification and the resulting hydrologic impacts. The discussion of genetic typing is framed around the geologic environment in Santa Clara County, California, but can be extended to a range of settings throughout California and beyond.

8.1.1 Tectogenic

Both sides of the Santa Clara Valley are within active fault zones. In active tectonic areas, active faults can bisect either the watershed, the pond, or both. Tectonism can create topographic depressions and sag ponds favorable for pond construction or enhancement by the ranchers to create stock watering ponds. Groundwater discharge through an active fault zone can consistently supply a Tectogenic pond with water, extending the hydroperiod.

8.1.2 Landslide Head Scarp

Large-scale slumps or scarps can leave wide, flat areas at the head, often exposing active groundwater seeps, the location of which may have contributed to the initial failure. Even though landslide head scarps are formed as a result of episodic geologic events, the timescale of these events may be considerably longer than engineering timescales for design of habitat improvements and should not be a primary concern for management of pond habitats. However, if considerable berm reconstruction were proposed, or observations point to hillslope instability, a geotechnical assessment may be required to address potential concerns. Active groundwater seep flow may extend the hydroperiod, but the loosely compacted landslide sediments deposited down-slope from the pond may result in a “leaky” and rapidly draining pond.

8.1.3 Mining or Quarry Depressions

Ponds created in mining or quarry depressions are entirely anthropogenic in nature, expressed as local topographic depressions resulting from excavation activities. Ponding can either be derived from surface runoff, excavated seeps or springs, or a both.

8.1.4 Instream

Many stock ponds in the Santa Clara county are ponds constructed in existing drainage channels or swales. Historically, the location of stock ponds was likely chosen by ranchers because favorable geologic or geomorphic conditions had previously narrowed the channel, caused a localized flatter channel slope, or perhaps hosted seeps and springs.

8.1.5 Landslide Dammed

Landslides can enter stream channels or swales and form in-channel dams. Landslide dams can be short-lived or persist for long periods of time. If the berm or landslide dam is routinely overtopped by surface flow, the impounding structure is typically eroded away and therefore may not be a good candidate for restoration management activities. Loosely compacted landslide deposits may create a leaky berm which may decrease the hydroperiod.

8.2 Interpreting Genetic Classifications

While genetic classification type is not an input into the model framework, and the model is currently designed to self-predict the inputs and outputs based on the calibration data, it is essential that users develop an understanding of the geologic and geomorphic conditions of site to field truth and interpret the model results. We recommend that, at a minimum, users reference a geologic map of the area to help interpret the local geology and geomorphic features. An excellent resource is the USGS National Geologic Map Database[4]. There is also no substitute for a trained geologist or geomorphologist and we recommend users seek assistance from trained professionals in those fields whenever feasible for assistance with interpreting model results within the context of the landscape and hydrologic function, and to assess what other processes might need to be considered for proper application of the model. Table 8-1 summarizes the model parameter implications for each of the genetic types listed above.

[4] https://ngmdb.usgs.gov/mapview/

Table 8-1 Summary of hydrologic implications for each Genetic Type of Pond

Genetic Type	Hydrologic Process(es) to Consider	Model Parameter Implication(s)
Tectogenic	Likely seep-fed sourced from fault or fracture pathways	- At least one groundwater module (Deep Fault Groundwater or Shallow Seep Groundwater) likely needed for good model fit - Local topographic depression or "sag" may result in higher Rainfall Fringe Area parameter
Landslide Head Scarp	Possibly seep-fed (may have contributed to landslide initialization); Possibly leaky pond through unconsolidated landslide deposit	- Perhaps one groundwater module (Deep Fault Groundwater or Shallow Seep Groundwater) needed for good model fit; - Leaky Pond Groundwater output parameter likely high
Mining or Quarry Depressions	Hydrologic processes dependent upon subsurface characteristics (Bedrock fractures? Mature soils or other aquitards?); Hydrologic response most likely a function of watershed size and precipitation vs ET	Varies
Instream	Hydrologic response most likely a function of watershed size and precipitation vs ET	- Groundwater modules (Deep Fault Groundwater or Shallow Seep Groundwater) likely not needed unless other signs of seeps or springs at site
Landslide Dammed	Similar to instream; but likely with leaky berm that is prone to erosion over time and thus degrading spillway elevation	- Groundwater modules (Deep Fault Groundwater or Shallow Seep Groundwater) likely not needed unless other signs of seeps or springs at site - Leaky Pond Groundwater output parameter likely high if berm is loosely compacted landslide deposit -A degrading spillway makes calibration difficult, if not impossible, depending on existing information.

REFERENCES

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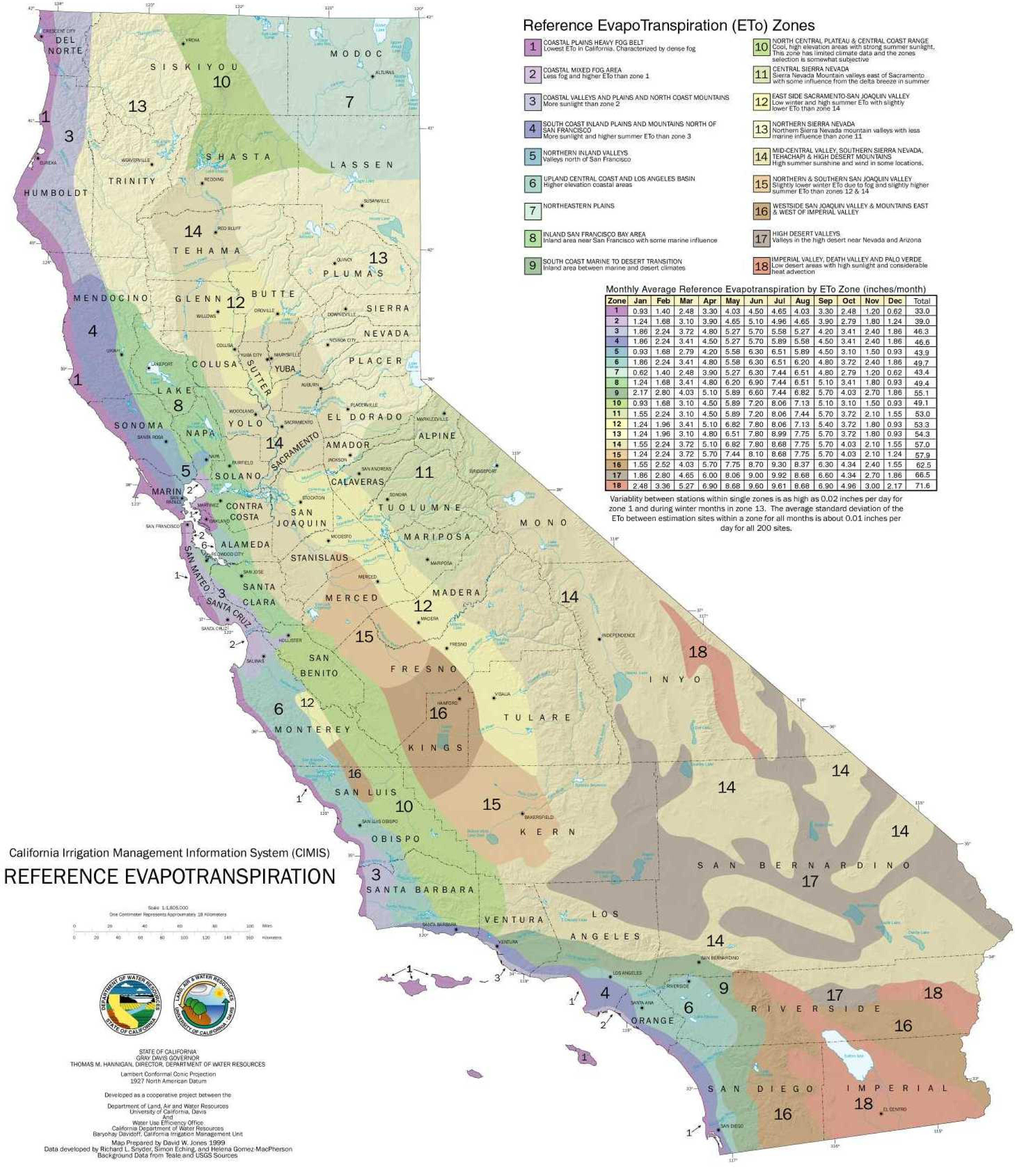
APPENDIX A

CIMIS Reference Evapotranspiration Map



Reference EvapoTranspiration (ETo) Zones

1 COASTAL PLAINS HEAVY FOG BELT
Lowest ETo in California. Characterized by dense fog

2 COASTAL MIXED FOG AREA
Less fog and higher ETo than zone 1

3 COASTAL VALLEYS AND PLAINS AND NORTH COAST MOUNTAINS
More sunlight than zone 2

4 SOUTH COAST INLAND PLAINS AND MOUNTAINS NORTH OF SAN FRANCISCO
More sunlight and higher summer ETo than zone 3

5 NORTHERN INLAND VALLEYS
Valleys north of San Francisco

6 UPLAND CENTRAL COAST AND LOS ANGELES BASIN
Higher elevation coastal areas

7 NORTHEASTERN PLAINS

8 INLAND SAN FRANCISCO BAY AREA
Inland area near San Francisco with some marine influence

9 SOUTH COAST MARINE TO DESERT TRANSITION
Inland area between marine and desert climates

10 NORTH CENTRAL PLATEAU & CENTRAL COAST RANGE
Cool, high elevation areas with strong summer sunlight. This zone has limited climate data and the zones selection is somewhat subjective

11 CENTRAL SIERRA NEVADA
Sierra Nevada Mountain valleys east of Sacramento with some influence from the delta breeze in summer

12 EAST SIDE SACRAMENTO-SAN JOAQUIN VALLEY
Low winter and high summer ETo with slightly lower ETo than zone 14

13 NORTHERN SIERRA NEVADA
Northern Sierra Nevada mountain valleys with less marine influence than zone 11

14 MID-CENTRAL VALLEY, SOUTHERN SIERRA NEVADA, TEHACHAPI & HIGH DESERT MOUNTAINS
High summer sunshine and wind in some locations.

15 NORTHERN & SOUTHERN SAN JOAQUIN VALLEY
Slightly lower winter ETo due to fog and slightly higher summer ETo than zones 12 & 14

16 WESTSIDE SAN JOAQUIN VALLEY & MOUNTAINS EAST & WEST OF IMPERIAL VALLEY

17 HIGH DESERT VALLEYS
Valleys in the high desert near Nevada and Arizona

18 IMPERIAL VALLEY, DEATH VALLEY AND PALO VERDE
Low desert areas with high sunlight and considerable heat advection

Monthly Average Reference Evapotranspiration by ETo Zone (inches/month)

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	33.0
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.4
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.0
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.3
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Variablity between stations within single zones is as high as 0.02 inches per day for zone 1 and during winter months in zone 13. The average standard deviation of the ETo between estimation sites within a zone for all months is about 0.01 inches per day for all 200 sites.

California Irrigation Management Information System (CIMIS)

REFERENCE EVAPOTRANSPIRATION

STATE OF CALIFORNIA
GRAY DAVIS GOVERNOR
THOMAS M. HANNIGAN, DIRECTOR, DEPARTMENT OF WATER RESOURCES

Lambert Conformal Conic Projection
1927 North American Datum

Developed as a cooperative project between the

Department of Land, Air and Water Resources
University of California, Davis
And
Water Use Efficiency Office
California Department of Water Resources
Baryohay Davidoff, California Irrigation Management Unit

Map Prepared by David W. Jones 1999
Data developed by Richard L. Snyder, Simon Eching, and Helena Gomez-MacPherson
Background Data from Teale and USGS Sources