WaterTAP3 Documentation

version 0.0.2

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Contents

WaterTAP3 Documentation

This is the documentation for the WaterTAP3 model.

WaterTAP3 Overview

The Water Technoeconomic Assessment Pipe-Parity Platform (WaterTAP3) was developed under the National Alliance for Water Innovation (NAWI) to facilitate consistent technoeconomic assessments of desalination treatment trains. It is an analytically robust modeling tool that can be used to evaluate cost, energy, and environmental tradeoffs of water treatment technology across different water sources, sectors, and scales.

WaterTAP3 is publicly accessible and based on open-source models and data. The model is designed to be flexible and customizable to allow users to adapt or create new treatment trains and process models to assess different water treatment performance criteria.

Examples of WaterTAP3 applications include:

- Baselining the state of water treatment systems across key water-using economic sectors.
- Road-mapping critical technology development priorities to achieve pipe parity.
- Performing ongoing project evaluation for NAWI funded research.
- Conducting technoeconomic and life-cycle assessments of water technologies and systems across the water industry (in development).

WaterTAP3 Installation

WaterTAP3 is still in development so is not listed in `pip` and must be accessed by cloning the current GitHub repo available at https://github.com/NREL/WaterTAP3.

1. **Install the Anaconda distribution of Python**:
    - https://www.anaconda.com/products/individual
2. **Create new empty directory for WaterTAP3 installation**:
    - e.g. this might be a folder called `wt3` on your desktop
3. **Open terminal and navigate to that directory**:
    - e.g. `cd ~/Desktop/wt3`
4. **Clone the repo**:
    - In terminal, enter `git clone https://github.com/NREL/WaterTAP3`
    - For example, if you cloned the repo into `~/Desktop/wt3` , you will have a new directory `~/Desktop/wt3/WaterTAP3`
    - All the necessary python files and data files will be downloaded into the `WaterTAP3` directory.
5. **Navigate to** `~/WaterTAP3`.
    - This directory contains the `watertap3.yml` file that is used to create the `watertap3` Python environment.

6. **Create the** `watertap3` **Python environment**.
    - In terminal, enter `conda env create --file watertap3.yml`
7. **Activate the** `watertap3` **Python environment**.
    - In terminal, enter `conda activate watertap3`
8. **Install the IDAES extensions to get solvers and function libraries**:
    - In terminal enter `idaes get-extensions`
9. **Navigate to** `~/WaterTAP3/watertap3`.
    - This directory contains the `setup.py` file that is used to install `watertap3` as an editable Python package.
    - For example, if you cloned the repo into `~/Desktop/wt3`, your working directory should now be `~/Desktop/wt3/WaterTAP3/watertap3`.
    - This is also the directory that contains this documentation.
10. **Install** `watertap3` **as an editable Python package**.
    - Must be in directory containing `setup.py` file
    - In terminal, enter `python –m pip install –e .`
    - **NOTE: MUST INCLUDE THE PERIOD AT THE END OF THIS COMMAND**
    - You should end up with new directory `watertap3.egg-info` in current directory
11. **Start Jupyter Notebook app or Jupyter Lab app to run WaterTAP3**.
    - For Jupyter Notebook - `jupyter notebook`
    - For Jupyter Lab - `jupyter lab`

Running WaterTAP3

Running WaterTAP3 is done in a Jupyter notebook via sequential execution of three functions. All proper imports must be made before running WaterTAP3.:

```
from watertap3.utils import watertap_setup, get_case_study, run_model, run_watertap3
import pandas as pd
import numpy as np
```

Prior to executing these functions, you must define four variables to be used as inputs to the functions:

- `case_study` - A string that must match the name of your case study in all input files.
- `scenario` - A string that must match the name of your scenario in all input files.
- `desired_recovery` - Targeted water recovery for your treatment train between 0-1 (default is 1).
- `ro_bounds` - A string that determines the maximum pressure limits for any reverse osmosis modules in your treatment train. Either `'seawater'` for higher pressure limits (up to 85 bar) or `'other'` for lower pressure limits (<25 bar). Default is `'seawater'`.

The series of function executions are

1. `m = watertap_setup(case_study=case_study, scenario=scenario)`
    - Reads in source water data and treatment train setup data.
2. `m = get_case_study(m=m)`
    - Connects units and creates inlet, outlet, and waste ports.
3. `m = run_watertap3(m, solver=solver, desired_recovery=desired_recovery, ro_bounds=ro_bounds)`
    - Runs WaterTAP3 model and saves results to `~/watertap3/watertap3/results/case_studies`.

This code block will execute all these steps.:

```
case_study = 'carlsbad'
scenario = 'baseline'
desired_recovery = 0.5
ro_bounds = 'seawater'
m = watertap_setup(case_study=case_study, scenario=scenario)
m = get_case_study(m=m)
m = run_watertap3(m, solver=solver, desired_recovery=desired_recovery, ro_bounds=ro_bounds)
```

WaterTAP3 Cost Estimates

Cost estimations are represented at the unit process level (i.e. per treatment technology in the train) and aggregated to the system-level. Estimated costs include:

- Capital investment
- Annual operation and maintenance
    - Fixed (labor, maintenance)
    - Variable (energy, chemical)

WaterTAP3 Outputs

The key performance metrics from WaterTAP3 currently include:

- Levelized Cost of Water (LCOW): cost per unit of treated water
- Energy intensity: direct energy consumption per unit of treated water
- Water recovery: the percentage of water recovered for a beneficial use
- Constituent removal: the percentage of constituent mass removed from the source water

Other outputs in development include:

- Extent of alternative water and energy resources
- Life-cycle assessment of environmental impacts (e.g. greenhouse gas emissions, total water intensity)
- System resiliency and security

WaterTAP3 Impacts

The objective of WaterTAP3 is to become a standard tool to evaluate water treatment system performance across key metrics used to promote and assess pipe-parity for a range of users including industry and academia. The results from WaterTAP3 can help identify trade-offs among the different performance metrics and enable users to asses how particular technologies affect pipe-parity metrics and how improvements in one metric can affect others across a range of source water conditions and technology performance parameters.

The flexibility and comprehensive scope of WaterTAP3 make it a useful tool for industry-wide technoeconomic analyses, promoting better informed water investment decisions and technology development. The tool can be used by policymakers, planners, and others without extensive analytical experience through the publicly available graphical user interface (under development).

WaterTAP3 Framework

WaterTAP3 simulates steady-state water treatment train performance and costs including flow and constituent mass balance across unit processes, based on source water conditions, configurations of treatment technologies, and system-level techno-economic assumptions. Capital costs, operating costs, and unit performance are estimated for both individual treatment processes and the system as a whole. Users can perform new analysis either by selecting an existing train from the treatment train library or connecting any number of unit processes together in a custom configuration.

The model contains various technical and cost parameter options for several treatment technology models and a library of influent water quality characteristics for a variety of source waters. Users can customize water quality parameters to evaluate technology performance for their unique conditions. The model can be used for different assessment needs, including process simulation, optimization, uncertainty analysis, and sensitivity analysis.

Model Structure

WaterTAP3 is implemented in Python using the Institute for the Design of Advanced Energy Systems (IDAES) which is itself based on the Python optimization and modeling package package Pyomo. Though initially developed for the research of innovative energy processes, at its core the IDAES framework is used to track material and energy flows through complex systems, making it useful for tracking water flows, chemical concentrations, and other parameters (e.g. pressure, temperature) through a treatment train.

Every WaterTAP3 model `m` is instantiated as a Pyomo `ConcreteModel()` object upon which an IDAES `FlowsheetBlock()` is placed to facilitate water and material transfers through each unit process in the WaterTAP3 model. Each unit model in WaterTAP3 is an instance of the `WT3UnitProcess()` class, which has properties inherited from the IDAES `UnitModelBlockData()` class. Connections between unit models are represented by the IDAES `Arc()` class.

Much like actual treatment technologies, material and energy exchanges in WaterTAP3 are facilitated by “ports” assigned to each unit process. Each water source and unit process is added as an attribute to the flowsheet and by default are given one inlet port, one outlet port, and one waste port. Additional inlet and outlet ports are added dynamically based on the input file (`treatment_train_setup.csv` - discussed in the Treatment Train Setup section of this documentation). Flow and mass balance is achieved across each unit process based on water recovery values and constituent removal factors.

Data Input for WaterTAP3

This section describes the data input .csv files contained in the `data` folder located in the `watertap3` directory. Many of these files applications and uses in WaterTAP3 are fully discussed in other sections, but their headings and a basic descriptions are presented here.

`basic_unit.csv`

This .csv file provides the inputs for unit process models that are initiated with the `basic_unit` module (fully discussed in the unit process section of this document).

Capital costs for basic units based on water or mass flow are calculated with the general form:

$$C_{basic} = af^b$$

The ratio of the unit water flow (or mass flow) to the basis water flow (or mass flow) is the scaling factor *f* used to scale the unit costs to the basis costs:

$$f = \frac{Q_{in}}{Q_{basis}}$$

More detail is available in the Basic Unit unit process documentation.

The headings for `basic_unit.csv` are:

- **unit_process**: The unit process name provided by user input.
- **flow_basis**: The flow basis for the unit process costing curve. This is either volume [m3/hr] or mass [kg/hr] based.
- **cap_basis**: The capital basis for the unit process costing curve.
- **cap_exp**: The exponent *b* for the costing curve.
- **elect**: Electricity intensity for the unit [kWh/m3]. This value is fixed.
- **year**: Costing year for the unit.
- **kind**: Indicates whether the unit is based on volumetric or mass flow.

`case_study_basis.csv`

This .csv contains the foundational technoeconomic assumptions for the entire treatment train. This input is also discussed in the Financial Basis Inputs section of this documentation and inputs from this data file are used throughout the Financials section of this documentation.

The file is arranged into the following columns:

- **case_study**: The treatment facility name.
- **scenario**: The name of the scenario that the TEA values correspond with
- **value**: The number or name of the variable of interest
- **reference**: The name of the project that is using the model
- **variable**: The name of the variable of interest

    - *analysis_year*: The first year of the plant is/was in operation
    - *location_basis*: The country or U.S. state where the plant is located. Used for assigning the electricity cost [$/kWh]. Electricity costs are provided in the data folder.
    - *plant_life_yrs*: The initial design basis for plant-life and used for life cycle analysis calculations. The default plant-life is 20 years.

- *land_cost_percent*: The assumed cost of land as a percentage of total fixed capital investment. This is a part of the total capital investment.
- *working_capital_percent*: The assumed cost of working capital as a percentage of total fixed capital investment. This is a part of the total capital investment.
- *salaries_percent*: The assumed cost of salaries as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *employee_benefits_percent*: The assumed cost of employee benefits as a percentage of total salary cost. This is a part of the fixed operating costs.
- *maintenance_cost_percent*: The assumed cost of maintenance as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *laboratory_fees_percent*: The assumed cost of laboratory fees as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *insurance_and_taxes_percent*: The assumed cost of insurance and taxes as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *default_cap_scaling_exp*: The typical value for economy-of-scale for capital equipment. This is a part of the total and fixed capital investment.
- *default_opex_scaling_exp*: The typical value for economy-of-scale for fixed plant costs. This is a part of the fixed operating costs.
- *cap_by_equity*: The percent of the capital that is financed by equity rather than debt. This is a part of the capital recovery factor and LCOW calculations.
- *debt_interest_rate*: The rate for loan financing of capital. This is a part of the capital recovery factor and LCOW calculations.
- *exp_return_on_equity*: The expected return, interest rate, or cost of capital associated with the portion of capital financed with equity.
- *default_tpec_multiplier*: The Total Purchased Equipment Cost (TPEC) to fixed capital investment. This is is a part of the total and fixed capital investment calculations.
- *default_tic_multiplier*: The Total Installed Cost (TIC) to fixed capital investment. This is a part of the total and fixed capital investment calculations.

case_study_water_sources.csv

Source water information is required to run the model. It can be selected from a list of pre-existing case studies or entered manually using Jupyter Notebook or the input data tables in this .csv file. There is no limit on the number of source water nodes for the model and the treatment train design section details how to connect source waters to the treatment train. Water flow rates (volumetric) and any constituent information required to calculate a unit process performance or cost must exist in the source water information.

The source water input dataset is arranged into the following columns:

- **case_study**: The treatment facility name.
- **scenario**: The name of the scenario that the values correspond with, otherwise the default value will be used.
- **water_type**: The type/source of the water. This is where the intake unit water_type names must match the train input water_type process parameter in the treatment train design.
- **variable**: The name of the constituent or property of interest, such as ‘flow’ (required) or ‘tds’.
- **value**: The number of the variable of interest
- **unit**: The units used for the constituent, such as kg/m3 (constituent concentration)
- **reference**: The name of the project.

catalyst_chemicals.csv

This .csv contains the price data used to calculate chemical and catalyst costs. WaterTAP3 uses the unit per volume (typically a dose as kg/m3) and the price in this .csv to calculate costs. More information on how this file is used is in the Variable Operating Costs section of this documentation.

The columns are:

- **Material**: Name of the material, catalyst, or chemical used in the unit process. Note that when user input is required for a catalyst or chemical (e.g. in the Chlorination unit module), the input must match *exactly* with the name in this column.
- **Price_Units**: The units associated with the Price column. Typically $/kg.
- **Price**: The price per unit used to calculate costs.
- **Price_Year**: The pricing year. Used to calculate a chemical index factor.
- **Purity**: The purity of the chemical used for pricing.

chemical_addition.csv

This .csv contains data used to construct costing curves for different chemicals in the `chemical_addition` unit module. A user could add an entry to this .csv if there is a chemical that is not represented here if they have a value for each column. More information on how this unit works is provided in the `chemical_addition` unit module.

The columns are:

- **chem_name**: Name of the material, catalyst, or chemical used in the unit process. Note that the chemical name provided by user input must match *exactly* with the entry in this column.
- **base**: The costing basis for the chemical addition used to construct the costing curve.
- **exp**: The exponent for the chemical addition used to construct the costing curve.
- **ratio**: The ratio of the chemical in the solution used in the source costing data.
- **density**: The density [kg/m3] of the chemical in the solution used in the source costing data.

chlorine_dose_cost.csv

This .csv contains costing data used in the `chlorination` unit module. This data is used as the basis to calculate the capital costs for chlorination based on unit flow and chlorine dose. The data in this file comes from the User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0.

The columns are:

- **Cost**: The cost associated with the dose and flow [$1000].
- **Dose**: The chlorine dose used for costing [mg/L].
- **Flow_mgd**: The flow used for costing [MGD].

constituent_removal.csv

This .csv contains default and case specific constituent removal factors. More information on how these factors are used is discussed in the Constituent Removal section of this documentation.

The columns are:

- **case_study**: The treatment facility name.
- **scenario**: The name of the scenario associated with the removal fraction.
- **units**: The units used for the constituent, such as kg/m3 (constituent concentration).
- **unit_process**: The unit process with the associated removal.
- **value**: The fraction or percent of the constituent in the source water that will be removed.
- **constituent**: The constituent being removed as named in the model.

- **calculation_type**: How the model will handle the values when the unit process changes the constituent level, ultraviolet transmittance, or pH.
    - *fractional_constituent_removal*: fractional removal
    - *absolute_value*: percent removal for ultraviolet transmittance
    - *delta_constituent_or_property*: when the pH is changed
- **reference**: The name of the project that is using the model.
- **data_reference**: The source of the data values and how values were calculated. Not used in the model but presented for user reference.
- **constituent_longform**: The longform name of the constituent. Not used in the model but presented for user reference.

`epa_cost_curves.csv`

This .csv contains summary outputs for different EPA model runs at different flow rates. The EPA models can be found at https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Outputs from these EPA models is used for the following WaterTAP3 unit modules:

- Cation Exchange
- Anion Exchange
- Fixed Bed Pressure Vessel
- Fixed Bed Gravity Basin
- Multi-Stage Bubble Aeration
- Packed Tower Aeration
- GAC - Pressure Vessel
- GAC - Gravity

Further explanation of how this data is used in those unit models is provided in the documentation for each respective unit. In short, data from the `flow_in`, `cap_total`, and `electricity_intensity` columns are used to construct cost curves as a function of flow [m3/hr] to determine capital costs and electricity intensity for each of these units.

The columns are:

- **unit_process**: The name of the WaterTAP3 unit module.
- **flow_in**: The flow [m3/hr] used to construct the cost curve.
- **cap_total**: Summation of the direct, indirect, and add-on costs from the EPA model runs.
- **electricity_intensity**: Electricity intensity data from EPA model runs.
- **tds_in**: Used by the Cation Exchange and Anion Exchange unit model to select the proper cost curve to use for the given TDS into the unit. If the unit does not have an entry in this column, it is not a function of this variable.
- **num_stage**: Used by the Multi-Stage Bubble Aeration unit model to select the proper cost curve based on the number of stages in the unit (determined from user input). If the unit does not have an entry in this column, it is not a function of this variable.
- **radon_rem**: Used by the Packed Tower Aeration unit model to determine the proper cost curve based on the target amount of radon removal (determined from user input). If the unit does not have an entry in this column, it is not a function of this variable.
- **ebct**: Used by the GAC - Gravity and GAC - Pressure Vessel unit models to determine the proper cost curve to used based on the EBCT (determined from user input). If the unit does not have an entry in this column, it is not a function of this variable.

The columns to the right of `ebct` are materials names specific to each unit model that uses this .csv. If there is no entry for the unit model under one of these columns, that unit model does not use that chemical. For example, the Cation Exchange unit model uses Ion_Exchange_Resin, but does not use Acetic_Acid. The values in each of these columns correspond to a dose for that chemical. WaterTAP3 takes the average of the entire column as the dose for that material or chemical which is then used to calculate chemical costs.

electricity_costs.csv

This .csv contains location specific electricity costs used to determine the electricity costs for the model. These costs are based on the industrial electricity cost rates reported by the U.S . Energy Information Administration.

The columns are:

- **location**: The location for the case study determined from the `case_study_basis.csv`.
- **cost**: The $/kWh price of electricity in that location.

ozone_cost_data.csv

Contains data from User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0 used to calculate ozone capital costs as a function of flow and ozone dose. The first column is the flow in MGD and the numbered columns correspond to an ozone dose. The capital costs are presented in thousands of dollars.

plant_cost_indices.csv

This .csv contains costing indices data.

There are four types of cost indices applied in WaterTAP3 – Capital, Catalysts and Chemicals, Labor and Consumer Price Index. WaterTAP3 calculates each of these indices for 1990-2050. These factors are used to help account for the time-value of investments and are used in the capital and operating cost calculations.

- **Year**: The year for the costing index.
- **Capital_Index**: The capital index for the given year.
- **CatChem_Index**: The catalyst and chemical index for the given year.
- **Labor_Index**: The labor index for the given year.
- **CPI_Index**: The consumer price index (CPI) for the given year.

Further information on how these values are used in WaterTAP3 is available in the Costing Indices and Factors section of this documentation.

treatment_train_setup.csv

This .csv is how treatment trains are setup in WaterTAP3. Please refer to the Treatment Train Setup section of this document for an in-depth description of this file and how it is used to create custom treatment trains in WaterTAP3.

uv_cost_interp.csv

Contains interpolated data from User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0 used to calculate the capital costs of a UV/AOP system as a function of flow, dose, and UV transmittance.

The columns are:

- **dose**: The UV dose [mJ/cm2] (from user input) used to determine capital costs.
- **flow**: The flow [MGD] used to determine capital costs.
- **uvt**: The UV Transmittance (from user input) used to determine capital costs.
- **cost**: The cost [$1000] as a function of dose, flow, and UVT.

More information in the UV + AOP model documentation.

water_recovery.csv

This .csv contains fractions of water recovery for each unit in WaterTAP3. More information on how this data is used in WaterTAP3 is available in the Water Recovery section of this documentation.

The columns are:

- **case_study**: The treatment facility name or default
- **scenario**: The name of the scenario that the values correspond with
- **unit_process**: The name of the unit process corresponding to the recovery value.
- **recovery**: How much water is recovered by each unit process (%)
- **reference**: The source of the recovery data

Model Output for WaterTAP3

This section describes the model results files and directory.

Directory Structure

Directory structure for results:

```
source/
| -- baseline/
|     | -- casestudy_baseline.csv (Case study specific baseline full results.)
|     | -- source_baseline_results.csv (Combined results for all case studies.)
|     | -- summary_table_source_baseline.csv (Key baseline results for source water.)
|     | -- figures/  (Treatment category level results)
|     |     | -- Annual O&M Costs_baseline
|     |     | -- Electricity Intensity System Treated_baseline
|     |     | -- LCOW_Cost_Category
|     |     | -- Total Capital Investment (TCI)_baseline
|     |     | -- Treatment Category LCOW_baseline
|     | -- csvs/
|     |     | -- CSV files used to create figures in “figures” directory
|     | -- by_unit/
|     |     | -- CSV and figures for key cost results by unit process.
| -- baseline_and_whatifs/
|     | -- Same structure as baseline folder but for both baseline and what-if scenarios.
| -- sensitivities/
|     | -- source_sensitivities.csv (Combined results of all sensitivity analysis.)
|     | -- casestudy_scenario_sensitivity.csv (Sensitivity results.)
```

Results File

Flow rates, constituent levels, and key cost attributes are reported for each unit process in a treatment train. System-level metrics including aggregate costs, energy use, recovery rate, and Levelized Cost of Water (LCOW) are also included.

The results table is arranged into the following columns (bold):

Unit Process Name: The unit process name or “System”.

Variable: The variable name that corresponds to the value. Examples are:

- Electricity Intensity [kWh/m3]
- Total Capital Investment (TCI) [$MM]
- Catalysts and Chemicals [$MM/yr]
- Electricity [$MM/yr]
- Other Variable Operating [$MM/yr]
- Fixed Operation [$MM/yr]
- Annual O&M Costs [$MM/yr]
- Inlet Water [m3/s]
- Outlet Water [m3/s]
- Waste Water [m3/s]
- Names of constituents in the source water [kg/s] and [kg/m3]

Example results for the entire treatment train are:

- System Total Capital Investment (TCI) [$MM]
- System Catalyst and Chemical Cost [$MM]
- System Electricity Cost [$MM]
- System Catalyst and Chemical Cost (Annual) [$MM/yr]
- System Electricity Cost (Annual) [$MM/yr]
- System Total Operating Cost (Annual) [$MM/yr]
- System LCOW [$/m3]
- System Electricity Intensity [kWh/m3]
- Water Recovery [%]

Value: The model result for the Variable in that row

Metric: The category for what is being measured. Examples are:

- Electricity
- Cost
- Annual Cost
- Water Flow
- Inlet Concentration
- Outlet Concentration
- Waste Concentration
- Inlet Mass Flow
- Outlet Mass Flow
- Waste Mass Flow

Unit: The units used for the results value. Examples are:

- LCOW: $/m3
- Electricity intensity: kWh/m3
- Total costs: $MM
- Annual costs: $MM/yr
- Flow rates: m3/s
- Water constituents: kg/s, kg/m3

Unit Kind: Intake, treatment process, or end-use as represented in the model

Treatment Category: Influent Storage and Pumping, Pre-treatment, Principal treatment, Product Storage, Product Distribution, Waste Treatment and Valorization, Waste Product Storage and Disposal, Post-treatment

Case Study: The treatment facility name

Scenario: The name of the scenario that the values correspond with ex. baseline or what-if scenarios

Note: the **python_var** and **python_param** columns are presented for ease of access if the user wants to access these results programatically. If the Unit Process Name is “System,” the **python_param** column is the name of the Variable in the model. The **python_var** is the name of the unit on the flowsheet and is also the name of the unit from the input sheet.

Sensitivity Analysis File

Results files for sensitivity analysis are arranged into the following columns Sensitivity results columns:

- **sensitivity_var** – indicates the variable around which sensitivity was done:

        - plant_cap = Plant Capacity Utilization
        - wacc = Weighted Average Cost of Capital (WACC)
        - tds_in = TDS concentration into treatment train
        - flow_in = volumetric flowrate into treatment train
        - plant_life = plant lifetime
        - elect_price = electricity price
        - component_replacement = maintenance cost as a percentage of FCI
        - If there was sensitivity around a reverse osmosis unit, an entry in this column is:
            - [RO unit name from input sheet]_[sensitivity variable]
            - e.g. if the RO is named “ro_first_pass” and sensitivity was around the pressure, the entry would be “ro_first_pass_pressure”
            - RO sensitivity variables:
                - membrane_area = area for the RO unit
                - pressure = feed pressure for RO unit
                - factor_membrane_replacement = membrane replacement factor for RO unit

- **baseline_sens_value** – the value of the sensitivity variable specified in “sensitivity_var” column used in the baseline model
- **scenario_value** – the value of the sensitivity variable specified in “sensitivity_var” column used in the sensitivity analysis used to generate results for that row
- **sensitivity_var_norm** – the value of the sensitivity variable in the sensitivity analysis relative to the value in the baseline analysis
- **lcow** – system LCOW for the sensitivity analysis
- **lcow_norm** – system LCOW for the sensitivity analysis normalized to the LCOW for the baseline case (LCOWsens / LCOWbaseline)
- **lcow_diff** – difference between sensitivity LCOW and baseline LCOW (LCOWsens - LCOWbaseline)
- **baseline_lcow** – LCOW for the baseline analysis
- **water_recovery** – system water recovery for the sensitivity analysis
- **water_recovery_difference** – difference between water recovery in the sensitivity analysis and in the baseline analysis
- **treated_water_vol** – treated water flow [m3/s] for the sensitivity analysis
- **baseline_treated_water** – treated water flow for the baseline analysis
- **treated_water_norm** – treated water flow for sensitivity analysis relative to the treated water flow for the baseline analysis (Qsens / Qbaseline)
- **elec_lcow** – electricity LCOW for the sensitivity analysis
- **elec_lcow_difference** – difference between electricity LCOW for the sensitivity analysis and the baseline analysis
- **baseline_elect_int** – system electricity intensity for the baseline analysis
- **elec_int** – system electricity intensity for the sensitivity analysis
- **elect_int_norm** – system electricity intensity for the sensitivity analysis relative to the system electricity intensity for the baseline analysis (Esens / Ebaseline)
- **scenario_name** – the name of the sensitivity analysis scenario in a more human-readable form
- If there was sensitivity around a reverse osmosis unit:

- **ro_pressure** – feed pressure for the RO unit for sensitivity analysis
- **ro_press_norm** – feed pressure for the RO unit for sensitivity analysis relative to feed pressure for the RO unit for the baseline analysis
- **ro_area** – membrane area for the RO unit for sensitivity analysis
- **ro_area_norm** – membrane area for the RO unit for sensitivity analysis relative to membrane area for the RO unit for the baseline analysis
- **mem_replacement** – membrane replacement factor used in sensitivity analysis
- **Note**: these columns are empty if the sensitivity analysis was not done around an RO unit

Source Water

`data/case_study_water_sources.csv`

Source water information is required to run the model. It can be selected from a list of pre-existing case studies or entered manually using Jupyter Notebook or the input data tables in the data folder. There is no limit on the number of source water nodes for the model and the treatment train design section details how to connect source waters to the treatment train. Water flow rates (volumetric) and any constituent information required to calculate a unit process performance or cost must exist in the source water information.

The source water input dataset is arranged into the following columns:

- **units**: The units used for the constituent, such as kg/m3 (constituent concentration)
- **value**: The number of the variable of interest
- **water_type**: The type/source of the water. This is where the intake unit water_type names must match the train input water_type process parameter in the treatment train design.
- **case_study**: The treatment facility name.
- **reference**: The name of the project.
- **variable**: The name of the constituent or property of interest, such as ‘flow’ (required) or ‘tds’.
- **scenario**: The name of the scenario that the values correspond with, otherwise the default value will be used.

Treatment Train Setup

`data/treatment_train_setup.csv`

This is the input file used to arrange and connect unit processes in the proper order and with the proper flows to create a treatment train according to the user's design.

The columns are:

- **CaseStudy**: The treatment facility name.
- **Reference**: The name of the project that is using the model.
- **Scenario**: The name of the scenario that the values correspond with, used to match water recovery and constituent removal rates specific to the case study-scenario combination.
- **Unit**: The unit process to be added to the train. The unit name in this column must match the exact naming convention of the unit process in the WaterTAP3 model.
- **Type**: The role of the unit process along the treatment train.
    - Options are "intake", "treatment", "use", or "waste"
    - "intake" types are declared for units that begin the treatment train and require at least one source water.
    - "use" types are declared for units considered to have a treated water product. The volume of water that goes through these units is used to calculate LCOW. Therefore, there must be at least one unit declared as the use with a flow rate greater than zero. These units do not have an outlet or waste port connected to another unit (i.e. they are a terminal unit)
    - "treatment" types are declared for treatment units. These units can have any number of inlet, outlet, and waste ports.
    - "waste" types are declared for units that handle terminal waste streams for the facility. These units can have any number of inlet ports but don't have outlet or waste ports that connect to another unit (i.e. they are a terminal unit).
- **UnitName**: The unit process name as defined by the user.
    - Each unit name must be unique. For example, if there are two of the same unit processes under the **Unit** column (e.g. `chlorination`), the first chlorination unit name could be `chlorination_a` and the second could be `chlorination_b`. The unit in this column is connected to the unit defined in the **ToUnitName** column.
- **ToUnitName**: The **UnitName** for a unit process in a different row that connects to the **UnitName** for the current row. The user can include any number of destination units by including them in this column separated by a column and with *no space in between*.
    - Example: If the user wanted `media_filtration` to split outlet flow 50/50 to `anti_scalant_addition` and `chlorination_b`, they would put `anit_scalant_addition,chlorination_b` in the **ToUnitName** column for the `media_filtration` row.
    - This is better explained in the example below.
- **FromPort**: For each unit process identified in the **ToUnitName** column, there needs to be a corresponding port, either "outlet" or "waste", that tells the model how to connect the current unit to the next unit in the train. If there is more than one port, the types are separated by a comma and *no space in between*.
    - Example: If the user wanted the treated flow from `media_filtration` to go to `anti_scalant_addition` and the waste flow to go to `backwash_solids_handling`, put `outlet,waste` in the **FromPort** column for the `media_filtration` row.

- **Parameter**: Used to characterize each unit process. All parameter formats are provided as python dictionaries, meaning the cell text must be enclosed by curly braces `{ }`, have quotation marks around parameter names, commas between each parameter, and a colon `:` separating the parameter name and the value for that parameter.
    - Example: If “`chemical_name`”, and `"dose"` are the parameter names, the proper format is:
        - `{'chemical_name': 'Chlorine', 'dose': 5}`
    - Specifics for required and optional unit parameters for each unit are provided in the documentation for each unit model.
    - If the value for an input parameter is a word (e.g. chemical name), it *must* be in single `' '` or double `" "` quotes. If it is a number, it *must not* be in quotes.

Treatment Train Example

Below is an example treatment train input file with various unit processes, flow splits, and waste streams.

	CaseStudy	Reference	Scenario	Unit	Type	UnitName	ToUnitName	FromPort	Parameter
2	example	nawi	baseline	well_field	intake	well_field	media_filtration	outlet	{'water_type': ['source_water']}
3	example	nawi	baseline	media_filtration	treatment	media_filtration	cartridge_filtration,anti_scalant_addition,landfill	outlet,outlet,waste	{'split_fraction': [0.65, 0.35]}
4	example	nawi	baseline	cartridge_filtration	treatment	cartridge_filtration	decarbonator	outlet	
5	example	nawi	baseline	anti_scalant_addition	treatment	anti_scalant_addition	ro_first_stage	outlet	{'dose': 5}
6	example	nawi	baseline	reverse_osmosis	treatment	ro_first_stage	decarbonator,ro_second_stage	outlet,waste	{'erd': 'no'}
7	example	nawi	baseline	reverse_osmosis	treatment	ro_second_stage	decarbonator,landfill	outlet,waste	{'erd': 'no'}
8	example	nawi	baseline	basic_unit	treatment	decarbonator	lime_softening	outlet	{'unit_process_name': 'decarbonator'}
9	example	nawi	baseline	lime_softening	treatment	lime_softening	chlorination	outlet	{'lime': 10}
10	example	nawi	baseline	chlorination	treatment	chlorination	treated_storage	outlet	{'chemical_name': 'Chlorine'}
11	example	nawi	baseline	holding_tank	treatment	treated_storage	municipal_drinking	outlet	{'avg_storage_time': 12, 'surge_cap': 0.2}
12	example	nawi	baseline	municipal_drinking	use	municipal_drinking			
13	example	nawi	baseline	landfill	waste	landfill			

- Row 2: `well_field` is the “intake” unit for the treatment train. All the flow from the `well_field` flows to `media_filtration`.
    - “intake” units must have a `water_type` in the **Parameter** column that corresponds to the proper source water found in `case_study_water_sources.csv`
    - The source water name must be in quotes and enclosed in brackets `[ ]` even if there is only one source water for the treatment train. This is to facilitate the inclusion of multiple source waters for a single intake.
- Row 3: Outlets for `media_filtration` flows to both `cartridge_filtration` and `ro_first_stage`. There is also a waste stream that flows to `landfill`.
    - The user can designate any split fraction they want in the **Parameter** column by using the `"split_fraction"` parameter.
    - Split fractions provided with `"split_fraction"` must be provided in brackets `[ ]` and the order of values in the split fraction correspond to the order of units in **ToUnitName**. In this case, 65% of the flow from `media_filtration` flows to `cartridge_filtration` and 35% flows to `anit_scalant_addition`.
    - The unit paramater `"split_fraction"` must be provided in **Parameter** even if the split is 50/50 (i.e. `{'split_fraction': [0.5, 0.5]}`).
- Row 4: Flow from `cartridge_filtration` flows to `decarbonator`.
    - Note that this flow stream is bypassing the two-stage reverse osmosis process. You can arrange flows in any configuration desired provided the input sheet is correct.

- Row 5: The chemical addition unit `anti_scalant_addition` receives 35% of flow from `media_filtration`
    - This unit requires a `"dose"` in the **Parameter** column.
- Row 6: The permeate stream from `ro_first_stage` flows to `decarbonator` and the reject (i.e. waste) stream flows to `ro_second_stage`
    - Note that the **ToUnitName** column does not match the **Unit** column. The user can provide any name they want for the unit in **ToUnitName**, but the **Unit** entry must match *exactly* the name of the Python file for that unit (without '.py' appended)
    - In this case, because there are two `reverse_osmosis` units, they must have different names for WaterTAP3 to correct the unit flows properly.
- Row 7: The permeate stream from `ro_second_stage` also flows to `decarbonator` and the reject (i.e. waste) stream flows to `landfill`
    - Both `reverse_osmosis` units require an `"erd"` parameter to indicate if the model should include an energy recovery device.
- Row 8: The `decarbonator` is receiving flows from `cartridge_filtration`, `ro_first_stage`, and `ro_second_stage`.
    - The `decarbonator` is a basic unit so must have a **Parameter** `"unit_process_name"` that matches the name of the desired unit in `basic_unit.csv`.
    - More information on basic units is provided in the basic unit documentation.
- Row 9-11: For each of these rows, 100% of the flow from the **UnitName** is flowing to **ToUnitName**.
    - Each have entries in **Parameters** as required.
- Row 12: For this treatment train `municipal_drinking` is the "use". Any water that flows through this unit is used to calculate LCOW.
    - The **ToUnitName** is empty for "use" units since flow does not go anywhere from here. It is a terminal unit. Similarly, it does not need an entry in **FromPort**

Water Recovery

`data/water_recovery.csv`

Water recovery is represented as the fraction (between zero and one) of water recovered (treated) after it passes through a unit process. Case-study based water recovery is given for certain unit processes if the case study has a unique recovery rate, otherwise default values are used.

The water balance for a single unit incorporates the water recovery:

$$Q_{in}x_{wr} = Q_{out}$$

And if the overall water balance for each unit is:

$$Q_{in} = Q_{out} + Q_{waste}$$

Then the water flow for the waste stream is:

$$Q_{waste} = Q_{in}(1 - x_{wr})$$

The total system water recovery along a single stream in the train for all units is the product of the water recovery for every unit in the stream:

$$x_{wr,\,stream} = \prod_{i}^{n} x_{wr,\,i}$$

And therefore the outlet flow for the entire stream the system water recovery multiplied by the sum of all *k* source flows to the system:

$$Q_{out,\,stream} = x_{wr,\,stream} \sum_{i}^{k} Q_{in,\,i}$$

The columns of `data/water_recovery.csv` are:

- **case_study**: The treatment facility name or default
- **scenario**: The name of the scenario that the values correspond with
- **unit_process**: The name of the unit process corresponding to the recovery value.
- **recovery**: How much water is recovered by each unit process (%)
- **reference**: The source of the recovery data

Constituent Removal

`data/constituent_removal.csv`

Constituent removal *r* is represented as the fraction (between zero and one) of the mass of the constituent being removed after it is passes through a unit process. Case-study based constituent removal is given for certain unit processes if the case study has a unique removal rate, otherwise default value are used.

The constituent removal data table states how much each unit process in each treatment facility removes a given water constituent. The model uses the information about the constituents in the source water as well as the removal rates of each unit process given in this constituent removal table to calculate constituent levels in the output water.

The overall mass balance for a single constituent *i* flowing into a single unit is based on volumetric flow and constituent concentration *c*:

$$Q_{in}c_{in,i} = Q_{out}c_{out,i} + Q_{waste}c_{waste,i}$$

Any mass removed by the unit is assumed to flow out the waste outlet. Then the constituent removal is:

$$Q_{in}c_{in,i}r_i = Q_{waste}c_{waste,i}$$

And therefore the mass flow out of the unit (i.e. to the next unit process) can be calculated with:

$$Q_{out}c_{out,i} = Q_{in}c_{in,i}(1 - r_i)$$

The constituent removal input dataset is arranged into the following columns:

- **case_study**: The treatment facility name.
- **scenario**: The name of the scenario associated with the removal fraction.
- **units**: The units used for the constituent, such as kg/m3 (constituent concentration).
- **unit_process**: The unit process with the associated removal.
- **value**: The fraction or percent of the constituent in the source water that will be removed.
- **constituent**: The constituent being removed as named in the model.
- **calculation_type**: How the model will handle the values when the unit process changes the constituent level, ultraviolet transmittance, or pH.
    - *fractional_constituent_removal*: fractional removal
    - *absolute_value*: percent removal for ultraviolet transmittance
    - *delta_constituent_or_property*: when the pH is changed
- **reference**: The name of the project that is using the mode
- **data_reference**: The source of the data values and how values were calculated. Not used in the model but presented for user reference.
- **constituent_longform**: The longform name of the constituent. Not used in the model but presented for user reference.

Financials

This section describes the different costing and pipe parity metric outputs from WaterTAP3 and how they are calculated in the model.

Costing Indices and Factors

Costing indices are available in `plant_cost_indices.csv` located in the data folder. The headings are:

- *Year*: The year for the costing index.
- *Capital_Index*: The capital index for the given year.
- *CatChem_Index*: The catalyst and chemical index for the given year.
- *Labor_Index*: The labor index for the given year.
- *CPI_Index*: The consumer price index (CPI) for the given year.

There are four types of cost indices applied in WaterTAP3 – Capital, Catalysts and Chemicals, Labor and Consumer Price Index. WaterTAP3 calculates each of these indices for 1990-2050. These factors are used to help account for the time-value of investments and are used in the capital and operating cost calculations. The following index factors are calculated for each process model in the treatment train based on:

- The user input for Analysis Year (for Cost Indices). This value is consistent across the entire treatment train.
- The Basis Year for the specific Process Model, Catalyst, Chemical, Replacement Part or other purchased item. This value is process-model-dependent with potentially different values across unit models within a treatment train.

The four cost indices are (where *Y* is the year):

- Capital Cost Index Factor:

$$f_{cap} = \frac{Y_{analysis}}{Y_{model}}$$

- Chemical Cost Index Factor:

$$f_{chem} = = \frac{Y_{analysis}}{Y_{chem}}$$

- Labor Cost Index Factor:

$$f_{labor} = \frac{Y_{analysis}}{Y_{model}}$$

- Other Cost Index Factor:

$$f_{other} = \frac{Y_{analysis}}{Y_{model}}$$

There are also various assumed costing factors for each case study read in from `case_study_basis.csv`:

- Electricity price:

$$P$$

- Plant capacity utilization:

$$f_{util}$$

- Land cost as percent of FCI:

  f_{land}

- Working capital as percent of FCI:

  f_{work}

- Salaries as percent of FCI:

  f_{sal}

- Maintenance costs as percent of FCI:

  f_{maint}

- Laboratory costs as percent of FCI:

  f_{lab}

- Insurance/taxes as percent of FCI:

  f_{ins}

- Benefits as percent of salary:

  f_{ben}

- Assumed plant lifetime:

  L

- Weighted Average Cost of Capital (debt interest rate):

  $WACC$

Financial Basis Inputs

The case study basis input data table contains the foundational technoeconomic assumptions for the entire treatment train.

The input dataset is arranged into the following columns:

- **case_study**: The treatment facility name.
- **scenario**: The name of the scenario that the TEA values correspond with
- **value**: The number or name of the variable of interest
- **reference**: The name of the project that is using the model
- **variable**: The name of the variable of interest

  - *analysis_year*: The first year of the plant is/was in operation
  - *location_basis*: The country or U.S. state where the plant is located. Used for assigning the electricity cost [$/kwh]. Electricity costs are provided in the data folder.

- *plant_life_yrs*: The initial design basis for plant-life and used for life cycle analysis calculations. The default plant-life is 20 years.
- *land_cost_percent*: The assumed cost of land as a percentage of total fixed capital investment. This is a part of the total capital investment.
- *working_capital_percent*: The assumed cost of working capital as a percentage of total fixed capital investment. This is a part of the total capital investment.
- *salaries_percent*: The assumed cost of salaries as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *employee_benefits_percent*: The assumed cost of employee benefits as a percentage of total salary cost. This is a part of the fixed operating costs.
- *maintenance_cost_percent*: The assumed cost of maintenance as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *laboratory_fees_percent*: The assumed cost of laboratory fees as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *insurance_and_taxes_percent*: The assumed cost of insurance and taxes as a percentage of total fixed capital investment. This is a part of the fixed operating costs.
- *default_cap_scaling_exp*: The typical value for economy-of-scale for capital equipment. This is a part of the total and fixed capital investment.
- *default_opex_scaling_exp*: The typical value for economy-of-scale for fixed plant costs. This is a part of the fixed operating costs.
- *cap_by_equity*: The percent of the capital that is financed by equity rather than debt. This is a part of the capital recovery factor and LCOW calculations.
- *debt_interest_rate*: The rate for loan financing of capital. This is a part of the capital recovery factor and LCOW calculations.
- *exp_return_on_equity*: The expected return, interest rate, or cost of capital associated with the portion of capital financed with equity.
- *default_tpec_multiplier*: The Total Purchased Equipment Cost (TPEC) to fixed capital investment. This is is a part of the total and fixed capital investment calculations.
- *default_tic_multiplier*: The Total Installed Cost (TIC) to fixed capital investment. This is a part of the total and fixed capital investment calculations.

System Capital Costs

The **Total Installed Costs (TIC)** are calculated for each individual unit process within the treatment train. This represents the cost of capital equipment plus the costs associated with installing the equipment in the plant. These include any costs associated with foundations, piping, insulation, assembly, buildings, electrical systems, and instrumentation. There are four approaches to calculating TIC in WaterTAP3, depending on the process, that vary in their level of detail:

- As a function of volumetric or mass flow only:
    - e.g. Basic units
- As function volumetric or mass flow and at least one other design criteria, such as chemical additions in which a dose is a required parameter:
    - e.g. chemical additions
- Based on physical performance/attributes of unit model, such as water recovery or constituent removal:

    - e.g. UV/AOP

- Multiple cost elements summed to calculate the TIC based on physical performance/attributes of unit model, such as pump and membrane costs for RO based on feed and osmotic pressures or evaporation pond costs that are based on evaporation rates, water recovery, and other design criteria:

    - e.g. Reverse osmosis

Depending on the costs assumed to be included in the unit's capital cost calculation (one of the four methods described above), some units may require additional cost multipliers to fully represent the TIC. For these units, the calculated capital cost is multiplied by either the **Equipment Installation Factor (EIF)** or the **Indirect Cost Factor (ICF)**. The EIF and ICF have default values of 3.4 (typical value range: 2.5-6.7) and 1.65 (typical value range: 1.2-1.7), respectively. After inclusion of either of these factors (if necessary), TIC is assumed to include indirect costs associated with constructing the process such as engineering costs, construction expenses, legal expenses, contractor fees, and contingencies. This is the **unadjusted Fixed Capital Investment**:

$$FCI_{unadj} = (EIF)TIC$$

Or:

$$FCI_{unadj} = (ICF)TIC$$

Then TIC is adjusted by the Capital Cost Index Factor (defined above) to get the FCI:

$$FCI = f_{cap}FCI_{unadj}$$

Finally, to arrive at the **Total Capital Investment (TCI)**, land costs and the working capital are added to the FCI:

$$TCI = FCI + C_{land} + C_{work}$$

Where:

$$C_{land} = f_{land}FCI$$

And:

$$C_{work} = f_{work}FCI$$

System Operating Costs

WaterTAP3 considers both variable and fixed operating costs. Variable operating costs are dependent on the flow rate and capacity utilization of each treatment technology, while fixed costs are dependent on the capital costs of the treatment facility.

Variable Operating Costs

Variable operating costs include any chemical additions, electricity costs, and other variable costs such as equipment replacements (e.g., membrane replacement costs for a reverse osmosis unit).

Chemical costs are based on the chemical dosage [kg/m3] as defined in the model or by the user for a given chemical addition. The costs of the chemicals can be found in the data folder. The annual chemical costs [$MM/yr] are calculated as:

$$C_{chem} = \sum_{k}^{n} D_k C_k Q_{in} f_{util}$$

Where D is the dose [kg/m3] of chemical k and C is the unit cost [$/kg] of chemical k as found in catalyst_chemicals.csv.

Electricity costs are based on the electricity intensity [kWh/m3] of each unit process, which is provided as a constant or calculated based on the configuration of the treatment process (see unit models for details). The annual electricity costs [$MM/yr] are calculated as:

$$C_{elec} = \sum_{k}^{n} E_k Q_{in} f_{util} P$$

Where E is the electricity intensity [kWh/m3] for unit k and P is the price of electricity for the locale [$/kWh], taken from the electricity_costs.csv data file.

There is also possibility for the inclusion of other operating costs that are unit specific. For most units, there are no costs included in this category.

Fixed Operating Costs

Employee salaries are calculated and scaled according to:

$$C_{sal} = f_{labor} f_{sal} FCI_{unadj}$$

Employee benefits are calculated according to:

$$C_{ben} = C_{sal} f_{ben}$$

Plant maintenance costs are calculated as:

$$C_{maint} = f_{maint} FCI$$

Plant laboratory costs are calculated as:

$$C_{lab} = f_{lab} FCI$$

Plant insurance and taxes are calculated according to:

$$C_{ins} = f_{ins} FCI$$

Total & Annual Operating Costs

The total fixed operating costs are calculated as:

$$C_{op,tot} = C_{sal} + C_{ben} + C_{maint} + C_{lab} + C_{ins}$$

And annual operating costs are:

$$C_{op,an} = C_{chem} + C_{elec} + C_{other} + C_{op,tot}$$

Pipe Parity Metrics

Levelized Cost of Water (LCOW)

The Levelized Cost Of Water (LCOW) [$/m3] is one of the primary pipe-parity metrics provided as an output from WaterTAP3.

$$LCOW = \frac{f_{recov} TCI + C_{op,an}}{V f_{util}}$$

With the capital recovery factor:

$$f_{recov} = \frac{WACC(1+WACC)^{L}}{(1+WACC)^{L} - 1}$$

And V is the total volume of treated water that goes toward a beneficial use. In WaterTAP3, this is the volume of water that flows through any unit designated as a "use" in the input sheet `treatment_train_setup.csv`.

The individual components that sum to the total LCOW are calculated as:

$$LCOW_{TCI} = \frac{f_{recov} TCI}{V_{treat} f_{util}}$$

The electricity LCOW is calculated as:

$$LCOW_{elec} = \frac{C_{elec}}{V_{treat} f_{util}}$$

The fixed operating LCOW is calculated as:

$$LCOW_{op} = \frac{C_{op,an}}{V_{treat} f_{util}}$$

The chemical cost LCOW is calculated as:

$$LCOW_{chem} = \frac{C_{chem}}{V_{treat} f_{util}}$$

The other cost LCOW is calculated as:

$$LCOW_{other} = \frac{C_{other}}{V_{treat} f_{util}}$$

The electricity intensity for the system is calculated as:

$$E_{sys} = \frac{C_{elec}}{P V_{treat}}$$

Variable Glossary

This section is a glossary of all the variables used to calculate costing and unit process parameters in unit process modules. Units for the same variable *may* not be identical from unit process to unit process, but variables and what they represent are consistent.

Economic Variables

- Cost (e.g. capital, operating):

  C

- Electricity price:

  P

- Equipment Installation Factor:

  EIF

- Capital Cost Index Factor:

  $f_{cap} = \frac{Y_{analysis}}{Y_{model}}$

- Chemical Cost Index Factor:

  $f_{chem} = = \frac{Y_{analysis}}{Y_{chem}}$

- Labor Cost Index Factor:

  $f_{labor} = \frac{Y_{analysis}}{Y_{model}}$

- Other Cost Index Factor:

  $f_{other} = \frac{Y_{analysis}}{Y_{model}}$

- Plant capacity utilization:

  f_{util}

- Land cost as percent of FCI:

  f_{land}

- Working capital as percent of FCI:

  f_{work}

- Salaries as percent of FCI:

  f_{sal}

- Maintenance costs as percent of FCI:

  f_{maint}

- Laboratory costs as percent of FCI:

  f_{lab}

- Insurance/taxes as percent of FCI:

  f_{ins}

- Benefits as percent of salary:

  f_{ben}

- Indirect Cost Factor:

  ICF

- Assumed plant lifetime:

  L

- Weighted Average Cost of Capital (debt interest rate):

  $WACC$

Unit Process Variables

- Area:

  A

- Concentration of constituent *i* into or out of a unit process:

  c_i

- Chemical dose:

  D

- Electricity intensity:

  E

- Efficiency (e.g., of motor, pump):

  η

- Factors/ratios:

  f

- Height:

  H

- Lift height (head) for pump:

  h

- Flux (e.g., solar, water):

  J

- Membrane permeability (water, salt):

  K

- Length:

  L

- Mass flow of constituent *i* into or out of a unit process:

  M_i

- Mass fraction of constituent *i*:

  m_i

- Number of unit processes:

  n

- Pressure:

  P

- Power:

  p

- Volumetric water flow into or out of a unit process:

  Q

- Volumetric air flow:

  q

- Rate:

  R

- Removal fraction or decay rate of constituent *i* associated with a unit process:

  r_i

- Density:

  ρ

- Chemical solution flow:

  S

- Osmotic coefficient:

  σ

- Temperature:

  T

- Time:

  t

- Volume:

  V

- Loading rate/velocity:

  v

- Generic capacity of unit process (e.g. mining, storage):

  X

- Unit water recovery:

  $x_{wr} = \frac{Q_{out}}{Q_{in}}$

- Depth:

  z

Unit Models

All unit processes achieve the mass balances described in the Water Recovery and Constituent Removal section. The calculations of water recovery and constituent removal are based on factors (discussed in the Data Input for WaterTAP3 section) or equations that represent some level of the physical processes that occur in the treatment process. There are four levels of detail (discussed also in the Financials section) across the unit models.

Agglomeration and Stacking

Agglomeration and stacking is the process of stacking metal-bearing ores for irrigation with a chemical solution.

Unit Parameters

There are two parameters:

- `"mining_capacity"` - mining capacity for the mine [tonnes/day]
    - Optional parameter
    - Default value is 922 tonnes/day
    - Must be provided with `"ore_heap_soln"` or default values for both will be used.
- `"ore_heap_soln"` - volume of leach solution needed per mass ore [gal/tonne]
    - Optional parameter
    - Default value is 500 gal/tonne
    - Must be provided with `"mining_capacity"` or default values for both will be used.

Capital Costs

Capital costs for agglomeration and stacking and other associated mine units (i.e. Solution Distribution and Recovery Plant, Heap Leaching) are derived from Table 3 in Kappes (2002). The costing components explicitly calculated for these units via regressed data from this table are (associated WaterTAP3 unit in parentheses):

- Mining equipment (Heap Leaching)
- Mine development (Heap Leaching)
- Crushing plant (Heap Leaching)
- Leaching pads/ponds (Heap Leaching)
- Agglomeration/stacking system (Agglomeration and Stacking)
- Solution distribution and recovery plant (Solution Distribution and Recovery Plant)

The costs from this table that are estimated as a fraction of the component costs are:

- Infrastructure (power, water, access roads, site office, service facilities)
- Owner’s preproduction cost
- Engineering, procurement, construction management
- Import duties
- Equipment and materials transport
- Initial operating supplies

Note that laboratory costs and working capital costs from this table are accounted for elsewhere in WaterTAP3 and so are excluded from the unit process calculations.

Capital costs for agglomeration and stacking are a function of the cost of the mining capacity X [tonnes/day]. This cost curve was derived from data for mining capacities of 3,000 tonnes/day and 15,000 tonnes/day from Table 3 in Kappes (2002):

$$C_{stack} = 0.00197X^{0.778}$$

To account for the other tabulated costing components in Table 3, WaterTAP3 calculates the fraction *f* that the other costs are of the component costs (i.e. other costs / component costs). The other costs fraction *f* are determined from a regression of the total cost in Table 3 minus the agglomeration and stacking costs (calculated above) vs. the mining capacities in that table (3,000 and 15,000 tonnes/day):

$$f = 0.3012X^{0.1119}$$

This fraction is multiplied by the agglomeration and stacking costs and added to those costs to form the costing basis:

$$C_{basis} = (C_{stack})(1 + f)$$

To create a cost curve based on unit flow, WaterTAP3 scales the unit flow to 65 m3/hr (derived from the initial heap leaching case study used to develop WaterTAP3). The final cost curve for agglomeration and stacking is:

$$C_{agglom} = \frac{Q_{in}}{65} C_{basis}^{0.778}$$

Operating Costs

The operating costs [$/year] for agglomeration and stacking are derived with cost curves regressed from data in Table 5 of Kappes (2002). Since this is the only component considered, this is the total operating cost:

$$C_{op} = 6.28846X^{0.56932}$$

Electricity Intensity

There is no electricity intensity associated with agglomeration and stacking.

References

Kappes, D.W. “Precious Metal Heap Leach Design and Practice” (2002)
in: *Mineral processing plant design, practice, and control*
pg. 1606-1630, ISBN: 0873352238
http://ore-max.com/pdfs/resources/precious_metal_heap_leach_design_and_practice.pdf

Agglomeration and Stacking Module

class `watertap3.wt_units.agglom_stacking.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Alum Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]
    - Required parameter

Capital Costs

The chemical solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single alum addition unit, *a* = 15408 and *b* = 0.5479. The full cost equation in WaterTAP3 is:

$$C_{alum} = 15408S^{0.5479}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.15 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

  h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

  $$M_{alum} = Q_{in}D_{alum}$$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3] and ratio of the chemical in the solution [v/v]:

  $$S = \frac{M_{alum}}{\rho_{alum}X_{alum}}$$

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as:

$$E_{alum} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2

- Solution density [kg/m3] = 1360
- Ratio in solution = 0.5
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Alum Addition Module

class `watertap3.wt_units.alum_addition.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

`fixed_cap` **(**unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘dose’: 10}

Parameters: **dose** (*float*) – Alum dose [mg/L]
Returns: Alum addition fixed capital cost [$MM]

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

`solution_vol_flow` **()**
Chemical solution flow in gal/day

Parameters:
- **solution_density** (*float*) – Alum solution density [kg/m3]
- **ratio_in_solution** (*float*) – Ratio of alum in solution

Returns: Alum solution flow [gal/day]

Ammonia Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]
    - Required parameter

Capital Costs

The ammonia solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a ammonia addition unit, *a* = 6699.1 and *b* = 0.4219. The full cost equation in WaterTAP3 is:

$$C_{amm} = 6699.1S^{0.4219}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters are rom Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{amm} = Q_{in}D_{amm}$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3] and ratio of the chemical in the solution [v/v]:

    $S = \frac{M_{amm}}{\rho_{amm}X_{amm}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{amm} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2

- Solution density [kg/m3] = 1360
- Ratio in solution = 0.5
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Ammonia Addition Module

class watertap3.wt_units.ammonia_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}
Fixed capital for ammonia addition is a function of ammonia dose, ammonia solution flow, and the number of units.

Parameters: **dose** (*float*) – Ammonia dose [mg/L]
Returns: Ammonia addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters:
- **solution_density** (*float*) – Solution density [kg/m3]
- **ratio_in_solution** (*float*) – Ratio of chemical in solution

Returns: Ammonia solution flow [gal/day]

Anion Exchange

The anion exchange model in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model (see reference). These models incorporate several aspects of cost of the treatment process, including treatment, monitoring, and administrative costs. Both capital cost and electricity intensity are based entirely on volumetric flow, but are assumed to incorporate these costing aspects of the EPA model.

The WBS EPA models each have some "standard designs" that make default assumptions (see EPA documentation) and span a range of flows 0.03 MGD to 75 MGD. Influent sulfate (called `tds_in` for WT3) also affects cost. The EPA model outputs several costing parameters, including total capital cost.

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of vthe EPA model standard designs using influent TDS of 200, 600, and 1000 mg/L. The different capital costs for each of these model runs is determined from the TDS into the unit, which is determined dynamically by WaterTAP3 (e.g. the cost curve is different if the influent TDS is 100 mg/L vs. 900 mg/L). A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve:

$$Y = aQ^b$$

Where Q is the flows for the standard design EPA models. Then a and b are used with the flow in for the particular case study.

Unit Parameters

None.

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{ax} = aQ_{in}^b$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$E_{ax} = aQ_{in}^b$$

Chemical Use

The WBS EPA model includes costs for sodium chloride and ion exchange resins. Rather than fit this data to a cost curve vs. standard design flows, the average is taken for the range of flows and assumed to be the "dose" for the particular chemical/material.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Anion Exchange Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-03/documents/wbs-anion-documentation-dec-2017_v3.pdf

Anion Exchange Module

class `watertap3.wt_units.anion_exchange.`**`UnitProcess`** (*args, **kwds)

`elect` **()**

Electricity intensity for anion exchange module [kWh/m3] :return:

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Anti-Scalant Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- `"dose"` - dose of chemical [mg/L]

    - Required parameter

Capital Costs

The model assumes Hydrazine as the anti-scalant. This unit is based off of costing parameters for sulfuric acid.

The anti-scalant solution flow S [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single anti-scalant addition unit, a = 900.97 and b = 0.6179. The full cost equation in WaterTAP3 is:

$$C_{anti} = 900.97S^{0.6179}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{anti} = Q_{in}D_{anti}$

- The volumetric flow S [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

    $S = \frac{M_{anti}}{\rho_{anti}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{anti} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2

- Solution density [kg/m3] = 1021
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Anti-Scalant Addition Module

class watertap3.wt_units.anti_scalant_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}

Returns: Anti-scalant addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]

Returns: Anti-scalant solution flow [gal/day]

Backwash Solids Handling

The backwash solids handling unit model represents the handling of the waste/backwash streams from filtration processes (e.g. tri-media filtration). It is typically recycled back into the treatment train or sent to a final waste unit.

Unit Parameters

There is one parameter for backwash solids handling:

- `"recovery"` - proportion of flow recycled back to treatment technology
    - Required parameter
    - Value between 0 and 1

Capital Costs

The costing for backwash solids handling is derived from combining costs for the following processes typically used to handle solids:

- Filter backwash pumping system
- Surface wash system
- Air scour system
- Wash water surge basins
- Wash water storage tank
- Gravity sludge thickener
- Sludge dewatering lagoons
- Sand drying beds

The assumed, cost per unit, number of units, and scaling factor for each of these processes was taken from Table 5.7.1 in McGivney & Kawamura (2008):

Process	Cost per unit	# Units	Total process cost	Scaling factor
Filter backwash pumping system	$186,458	2	$372,916	1.0
Surface wash system	$99,941	2	$199,882	1.0
Air scour system	$463,853	2	$927,706	1.0
Wash water surge basins	$770,643	1	$770,643	0.751
Wash water storage tank	$216,770	1	$216,770	0.847
Gravity sludge thickener	$94,864	1	$94,864	1.305
Sludge dewatering lagoons	$4,173	3	$12,519	0.714
Sand drying beds	$45,801	6	$274,806	0.875

Summation of the total cost column gives the cost basis of 9.76 and the scaling exponent is calculated as the summation of each entry for total process cost multiplied by the scaling factor divided by the summation of the scaling factors:

$$b_{bw} = \frac{\sum C_i * b_i}{\sum b_i} = 0.918$$

The capital costs are a function of mass flow [kg/hr]. The costing basis is for 100 MGD (15772.55 m3/hr) and assumes a density of 1000 kg/m3. Thus, the basis is 1577255 kg/hr:

$$C_{bw} = 9.76 \frac{M_{in}}{1577255}^{0.918}$$

The mass flow in is the sum of all the constituents flowing into the unit:

$$C_{in} = \sum_{i}^{n} c_i$$

Then, the density of the solution is [kg/m3]:

$$\rho_{in} = 0.6312(C_{in}) + 997.86$$

And mass flow is determined with [kg/hr]:

$$M_{in} = \rho_{in} Q_{in}$$

Electricity Intensity

Electricity intensity for backwash solids handling is based off the pump used. The calculation includes:

- Lift height [ft]:

  h

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

- And the influent flow in [gal/min] and [m3/hr]:

  Q_{gpm}, Q_{m3hr}

Then the electricity intensity is calculated as:

$$E_{bw} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{m3hr}}$$

Assumptions

- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Backwash Solids Handling Module

class `watertap3.wt_units.backwash_solids_handling.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Basic Unit

Capital costs for the units defined as “basic” are based entirely on either the volumetric or mass flow into the unit.

All of the data for each of the basic units is read in from the `basic_unit.csv` located in the data folder.

Unit Parameters

- `"unit_process_name"` - unit process name that is being represented as a basic unit.
    - Required parameter
    - Must be enclosed in double `"  "` or single `'  '` quotes
    - Must match *exactly* the entry in the `unit_process` column in `basic_unit.csv`

basic_unit.csv

This .csv file contains all of the data used to calculate fixed capital costs and electricity intensity for all basic units. The columns are:

- `unit_process` - unit process name in WaterTAP3
- `flow_basis` - flow basis from costing source [m3/hr]
- `cap_basis` - *a* fixed capital investment from costing source [$MM]
- `cap_exp` - *b* fixed capital investment scaling exponent
- `electricity_intensity` - electricity intensity for unit [kWh/m3]
- `year` - costing basis year
- `kind` - determines if unit is based on water flow or mass flow

Capital Costs

Flow Based

Capital costs for basic units based on water flow are calculated with the general form:

$$C_{basic} = af^b$$

The ratio of the unit water flow to the basis water flow is the scaling factor *f* used to scale the unit costs to the basis costs:

$$f = \frac{Q_{in}}{Q_{basis}}$$

Mass Based

For those units based on mass flow, the mass flowing into the unit must be determined. First we determine the concentration flowing into the unit [kg/m3], calculated as the summation of the concentration of all constituents entering the unit:

$$C_{in} = \sum_{i}^{n} c_i$$

Then, we estimate the density of the solution [kg/m3] from Bartholomew & Mauter (2019):

$$\rho_{in} = 0.6312(C_{in}) + 997.86$$

Mass flow [kg/hr] is determined with:

$$M_{in} = \rho_{in} Q_{in}$$

Capital costs for basic units based on mass flow are calculated with the general form:

$$C_{basic} = af^b$$

The ratio of the unit mass flow to the basis mass flow is the scaling factor *f* used to scale the unit costs to the basis costs:

$$f = \frac{M_{in}}{M_{basis}}$$

Electricity Intensity

Electricity intensity for basic units is read directly from the `electricity_intensity` column in `basic_unit.csv` (see above) and does not scale with flow (i.e. it is a fixed value).

List of Basic Units

- Treatment Technologies:
    - ABMET Intermediate Pumps
    - ABMET Interstage Pumps
    - Aeration Basins
    - Air Floation
    - Anaerobic Digestion Oxidation
    - Bio-Active Filtration
    - Bioreactor
    - Bioreactor BW Pump
    - Bioreactor Feed Pump
    - Bioreactor Effluent Pump
    - Blending Reservoir
    - Buffer Tank
    - Conventional Activated Sludge (CAS)
    - Clarifier
    - Decarbonators
    - Dissolved Air Flotation (DAF)
    - Drainage Sump Pumps
    - Filter Presses
    - Intrusion Mitigation
    - Membrane Bioreactors (MBR)
    - Microscreen Filtration
    - Nanofiltration (NF)
    - pH Adjustment
    - Raw Water Pumps
    - Screens
    - Separators
    - Settling Ponds
    - Settling Tanks
    - SMP
    - Transfer Pumps
    - Tramp Oil Tanks
    - Ultrafiltration (UF)
    - Ultratiltration Feed Pumps
    - WAIV
    - Walnut Shell Filter
- Uses/Waste Streams & Other:

- Agriculture
- Cooling Supply
- Discharge
- Industrial
- Intrusion Mitigation
- Injection Wells
- Irrigation
- Mining
- Municipal WWTP
- Passthrough

References

Bartholomew, T. V. and M. S. Mauter (2019).
“Computational framework for modeling membrane processes without process and solution property simplifications.”
Journal of Membrane Science 573: 682-693.

Basic Unit Module

class `watertap3.wt_units.basic_unit.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for basic units.

Returns: Electricity intensity [kWh/m3]

`fixed_cap` **()**

Parameters: **flow_in** (*float*) – Flow in to basic unit [m3/hr]

Brine Concentrator

The brine concentrator unit represents an evaporative (i.e. thermal) brine concentrator based on WateReuse Foundation (2008).

Unit Parameters

None.

Capital Costs

Capital costs for brine concentrators are a function of influent TDS, water recovery, and flow in. The regression is based on data found in Tables 5.1 and A2.3 found in WateReuse Foundation (2008).

$$C_{brine} = 15.1 + 3.02 \times 10^{-4}(c_{TDS}) - 18.8(x_{wr}) + 8.08 \times 10^{-2}(Q_{in})$$

Electricity Intensity

Electricity intensity is a function of the same variables and uses the same reference.

$$E_{brine} = 9.73 + 1.1 \times 10^{-4}(c_{TDS}) + 10.4(x_{wr}) + 3.83 \times 10^{-5}(Q_{in})$$

Reference

Mickley, Michael C. (2008)
“Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities”
WateReuse Foundation
ISBN: 978-1-934183-08-3

Brine Concentrator Module

class watertap3.wt_units.brine_concentrator.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity for brine concentrator.

Parameters:
- **tds_in** (*float*) – TDS concentration in to brine concentrator [mg/L]
- **water_recovery** (*float*) – Water recovery for the brince concentrator
- **flow_in** (*float*) – Water flow in to brine concentrator [m3/hr]

Returns: Electricity intensity [kWh/m3]

fixed_cap ()
Fixed capital for brine concentrator.

Parameters:
- **tds_in** (*float*) – TDS concentration in to brine concentrator [mg/L]
- **water_recovery** (*float*) – Water recovery for the brine concentrator
- **flow_in** (*float*) – Water flow in to brine concentrator [m3/hr]

Returns: Fixed capital cost for brine concentrator [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Cartridge Filtration

Unit Parameters

None

Capital Costs

The capital costs are a function of flow [MGD] with cost curve parameters from section 3.5.6, figure 3.3 in Texas Water Development Board (2016):

$$C_{cart} = 0.72557 Q_{in}^{0.5862}$$

Electricity Intensity

Electricity intensity for cartridge filtration is fixed at 2E-4 kWh/m3 and is taken from Bukhary, et al. (2019).

References

CAPITAL

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

Bukhary, S., Batista, J., Ahmad, S. (2019).
An Analysis of Energy Consumption and the Use of Renewables for a Small Drinking Water Treatment Plant.
Water, 12(1), 1-21.

Cartridge Filtration Module

class `watertap3.wt_units.cartridge_filtration.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Cation Exchange

The cation exchange model in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model (see reference). These models incorporate several aspects of cost of the treatment process, including treatment, monitoring, and administrative costs. Both capital cost and electricity intensity are based entirely on volumetric flow, but are assumed to incorporate these costing aspects of the EPA model.

The WBS EPA models each have some "standard designs" that make default assumptions (see EPA documentation) and span a range of flows 0.03 MGD to 75 MGD. Influent hardness (called `tds_in` for WT3) also affects cost. The EPA model outputs several costing parameters, including total capital cost.

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of vthe EPA model standard designs using influent TDS of 200, 600, and 1000 mg/L. The different capital costs for each of these model runs is determined from the TDS into the unit, which is determined dynamically by WaterTAP3 (e.g. the cost curve is different if the influent TDS is 100 mg/L vs. 900 mg/L). A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve:

$$Y = aQ^b$$

Where Q is the flows for the standard design EPA models. Then a and b are used with the flow in for the particular case study.

Unit Parameters

None.

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{cx} = aQ_{in}^b$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$E_{cx} = aQ_{in}^b$$

Chemical Use

The WBS EPA model includes costs for sodium chloride and ion exchange resins. Rather than fit this data to a cost curve vs. standard design flows, the average is taken for the range of flows and assumed to be the "dose" for the particular chemical.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Cation Exchange Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-03/documents/wbs-cation-documentation-dec-2017_v2.pdf

Cation Exchange Module

class `watertap3.wt_units.cation_exchange.`**`UnitProcess`** (*args, **kwds)

`elect` **()**

Electricity intensity for cation exchange module [kWh/m3] :return:

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Caustic Soda Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]
    - Required parameter

Capital Costs:

The caustic soda flow *S* [galday] is used in a cost curve of the general form:

$$C = aS^b$$

For a single caustic soda addition unit, *a* = 2262.8 and *b* = 0.6195. The full cost equation in WaterTAP3 is:

$$C_{NaOH} = 2262.8S^{0.6195}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.12b in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{NaOH} = Q_{in}D_{NaOH}$

- The volumetric flow ‘S’ [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

$$S = \frac{M_{NaOH}}{\rho_{NaOH}X_{NaOH}}$$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{NaOH} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1021
- Ratio in solution = 50%
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Caustic Soda Addition Module

class watertap3.wt_units.caustic_soda_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}

Parameters: **dose** (*float*) – Caustic dose [mg/L]
Returns: Caustic soda addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters:
- **solution_density** (*float*) – Solution density [kg/m3]
- **ratio_in_solution** (*float*) – Ratio of chemical in solution

Returns: Caustic soda solution flow [gal/day]

Generic Chemical Addition

This unit is for a generic chemical addition that does not have a specific unit model in WaterTAP3.

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

You can add any chemical you want to `catalyst_chemicals.csv` located in the data folder. The entry must include a price per kg and a year for the unit price.

Unit Parameters

There are four unit parameters:

- `"chemical_name"` - the name of the chemical to be added:
    - Required parameter
    - Must be in single `' '` or double `" "` quotes
    - Must match exactly an entry in `catalyst_chemicals.csv`. If it is not in that file, users can easily add a chemical by providing an entry for each column.
- `"dose"` - chemical dose [mg/L]:
    - Required parameter
    - Dose of chemical to be added
- `lift_height"` - dynamic head for chemical pump [ft]:
    - Optional parameter
    - Default value is 100 ft
- `"pump_eff"` and `"motor_eff"` - pump and motor efficiency:
    - Optional parameters
    - Default value for both is 0.9
    - Must be provided together or default value for both is used.

Capital Costs

The generic chemical addition module is based off costing parameters for sulfuric acid.

The chemical solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single unit, *a* = 900.97 and *b* = 0.6179. The full cost equation in WaterTAP3 is:

$$C_{chem} = 900.97S^{0.6179}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

  h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

  $M_{chem} = Q_{in} D_{chem}$

- The volumetric flow S [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

  $S = \frac{M_{chem}}{\rho_{chem}}$

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{chem} = \frac{0.746 S h}{3960 \eta_{pump} \eta_{motor} Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1000
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Chemical Addition Module

class `watertap3.wt_units.chemical_addition.`**`UnitProcess`** (*args, **kwds)

`elect` **(**unit_params**)**
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

`fixed_cap` **(**unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘dose’: 10}
Fixed capital for chemical addition is a function of chemical dose, chemical solution flow, and the number of units.

Parameters:
- **chemical_name** (*str*) – Chemical name to be used.
- **dose** (*float*) – Dose of chemical [mg/L]

Returns: Chemical addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]

Returns: Chemical solution flow [gal/day]

Chlorination

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There are two unit parameters:

- `"chemical_name"` - the name of the chemical for chlorination:
    - Required parameter
    - Must be in single `' '` or double `" "` quotes
- `"dose"` - chlorination dose [mg/L]:
    - Optional parameter
    - Default value is 9.5 mg/L (calculated below)

The following unit parameters must be provided together or the default values are used:

- `"contact_time"` - chlorination contact time [hr]:
    - Optional parameter
    - Default value is 1.5 hr
- `"ct"` - CT value [mg*min/L]:
    - Optional parameter
    - Default value is 450 mg*min/L
- `"chlorine_decay_rate"` - chlorine decay rate [mg/L*hr]:
    - Optional parameter
    - Default value is 3 mg/L*hr

Capital Costs

Chlorination capital costs are a function of the applied chlorine dose and the flow using data in Table 3.23 of the Texas Water Development Board (2016).

If `"dose"` is not provided by the unit parameters in the input sheet, the chlorine dose is calculated from:

$$D_{Cl} = d + rt + \frac{Ct}{t}$$

- d = Chlorine demand [mg/L]
- r = Chlorine decay rate [mg/Lhr]; default = 3
- t = Contact time [hr]; default = 1.5
- Ct = Desired Ct [mg*min/L]; default = 450

Then, using the data provided in Table 3.23 from the Texas Water Board reference, cost data is read in based on the dose and fit to the general form based on flow [MGD]:

$$C = aQ^b$$

In other words, values of *a* and *b* will depend on the dose used for the unit. Once *a* and *b* are known, the capital costs for chlorination are:

$$C_{Cl} = aQ_{in}^{b}$$

Electricity Intensity

Electricity intensity for chlorination is fixed at 5E-5 kWh/m3 and is taken from Bukhary, et al. (2019).

Assumptions

According to the reference, capital costs only include chemical feed equipment and assume there is sufficient contact time downstream of the chlorine feed point.

References

CAPITAL

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

Bukhary, S., Batista, J., Ahmad, S. (2019).
An Analysis of Energy Consumption and the Use of Renewables for a Small Drinking Water TreatmentPlant.
Water, 12(1), 1-21.

Chlorination Module

class `watertap3.wt_units.chlorination.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

`fixed_cap` **(**unit_params**)**

Parameters: **unit_params** – Unit parameters from input sheet.

Returns:

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Carbon Dioxide Addition

Unit Parameters

None

Capital Costs

The capital costs are a function of flow [MGD] from McGivney & Kawamura (2008):

$$C_{co2} = 0.464 Q_{in}^{0.7}$$

The 0.7 exponent is a generic exponent used to make order-of-magnitude cost estimates for processes where only the cost and flow (or capacity) are known from a previous facility that used the same process (Towler & Sinnott, 2021). | Electricity Intensity ————————

None.

References

CAPITAL

Gavin Towler & Ray Sinnott (ed.) (2021)
Chemical Engineering Design (Third Edition): Principles, Practice and Economics of Plant and Process Design
Chapter 7 - Capital cost estimating, pg 239-278
DOI: 10.1016/B978-0-12-821179-3.00007-8
ISBN: 9780128211793

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Carbon Dioxide Addition Module

class watertap3.wt_units.co2_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap ()

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Coagulant Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]
    - Required parameter

Capital Costs

The coagulant flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single alum addition unit, *a* = 15408 and *b* = 0.5479. The full cost equation in WaterTAP3 is:

$$C_{coag} = 15408S^{0.5479}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.15 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

  h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

  $M_{coag} = Q_{in}D_{coag}$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

  $S = \frac{M_{coag}}{\rho_{coag}X_{coag}}$

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{coag} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1360

- Ratio in solution = 50%
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Coagulant Addition Module

class watertap3.wt_units.coagulant_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}
Fixed capital for alum addition is a function of alum dose, alum solution flow, and the number of units.

Returns: Alum addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters:
- **solution_density** (*float*) – Solution density [kg/m3]
- **ratio_in_solution** (*float*) – Ratio of chemical in solution

Returns: Alum solution flow [gal/day]

Coagulation and Flocculation

Unit Parameters

The coagulation/flocculation module has two parameters:

- `"alum_dose"` - alum dose for the unit [mg/L]
    - Required parameter
- `"polymer_dose"` - polymer dose for the unit [mg/L]
    - Required parameter

Capital Costs

The coagulation/flocculation unit in WaterTAP3 includes costing for rapid mix, flocculation, coagulant injection, and flocculant injection:

$$C_{clf} = C_{rm} + C_{floc} + C_{floc,inj} + C_{coag,inj}$$

Rapid mix capital is calculated as:

$$C_{rm} = (7.0814 V_{rm} + 33269) n_{rm}$$

Where the rapid mix basin volume is calculated with [gal]:

$$V_{rm} = Q_i n$$

Flocculation capital is calculated as:

$$C_{floc} = (952902 V_{floc} + 177335) n_{floc,proc}$$

Where the flocculation basin volume is calculated with [gal]:

$$V_{floc} = Q_{in} t_{floc}$$

Flocculation injection capital is calculated as:

$$C_{floc,inj} = (13662 Q_{poly} + 20861) n_{floc,inj}$$

Where the flow of polymer is calculated with [lb/hr]:

$$Q_{poly} = D_{poly} Q_{in}$$

Coagulant injection capital is calculated as:

$$C_{coag,inj} = (212.32 Q_{alum} + 73225) n_{coag}$$

Where the flow of alum is calculated with [lb/hr]:

$$Q_{alum} = D_{alum} Q_{in}$$

Assumptions

Several aspects of the unit are assumed:

There is one rapid mixers per process and one rapid mix process:

$$n_{rm} = n_{rm,\,proc} = 1$$

The rapid mix retention time is 5.5 sec:

$$t_{rm} = 5.5$$

There are three flocculation mixers, two floc processes, and one floc injection process:

$$n_{floc} = 3, n_{floc,\,proc} = 2, n_{floc,\,inj} = 1$$

The flocculation retention time is 12 minutes:

$$t_{floc} = 12$$

There is one coagulant process:

$$n_{coag} = 1$$

The cationic polymer dose and the anionic polymer dose are each equal to half the user provided `"polymer_dose"` [mg/L]:

$$D_{cat} = D_{an} = 0.5 D_{poly}$$

Electricity Intensity

The total electricity intensity for coagulation/flocculation includes rapid mix power and flocculation power [kWh/m3]:

$$E_{c/f} = \frac{p_{rm} + p_{floc}}{Q_{in}}$$

With rapid mix power calculated with the rapid mix basin volume in m3 [W]:

$$p_{rm} = (0.001 V_{rm} 900^2) n_{rm}$$

And flocculation power calculated with the flocculation basin volume in m3 [W]:

$$p_{floc} = (0.001 V_{floc} 80^2) n_{floc}$$

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Coagulation and Flocculation Module

class `watertap3.wt_units.coag_and_floc.`**`UnitProcess`** (*args, **kwds)

`elect` **()**

Electricity intensity for coagulation/flocculation [kWh/m3]

Returns:

fixed_cap (unit_params**)**

Parameters: **unit_params** (*dict*) – Input parameters from input sheet

Returns:

get_costing (unit_params=None**,** year=None**)**

Initialize the unit in WaterTAP3.

Crystallizer

The crystallizer represents a thermal crystallizer and is based on WateReuse Foundation (2008) data.

Unit Parameters

None.

Capital Costs

Capital costs for crystallizers are a function of influent TDS, water recovery, and flow in.

The regression is based off of data found in Tables A2.1 and A2.3 found in WateReuse Foundation (2008).

$$C_{cryst} = 1.41 - 7.11 \times 10^{-7}(c_{TDS}) + 1.45(x_{wr}) + 0.56(Q_{in})$$

Electricity Intensity

Electricity intensity is a function of the same variables and uses the same reference.

$$E_{cryst} = 56.7 + 1.83 \times 10^{-5}(c_{TDS}) - 9.47(x_{wr}) - 8.63 \times 10^{-4}(Q_{in})$$

Reference

Mickley, Michael C. (2008)
“Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities”
WateReuse Foundation
ISBN: 978-1-934183-08-3

Crystallizer Module

class watertap3.wt_units.crystallizer.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity for crystallizer.

Parameters:
- **tds_in** (*float*) – TDS concentration in to crystallizer [mg/L]
- **water_recovery** (*float*) – Water recovery for the crystallizer
- **flow_in** (*float*) – Water flow in to crystallizer [m3/hr]

Returns: Electricity intensity [kWh/m3]

fixed_cap ()
Fixed capital for crystallizer.

Parameters:
- **tds_in** (*float*) – TDS concentration in to crystallizer [mg/L]
- **water_recovery** (*float*) – Water recovery for the crystallizer
- **flow_in** (*float*) – Water flow in to crystallizer [m3/hr]

Returns: Fixed capital cost for crystallizer [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Deep Well Injection

Deep well injection is used to dispose of waste streams.

Unit Parameters

Deep well injection has two parameters:

- `"lift_height"` - dynamic head for injection pump [ft]:
    - Optional parameter
    - Default value is 400 ft
- `"pipe_distance"` - pipe distance from facility to deep well injection site [mi]
    - Required parameter

Capital Costs

Capital costs for deep well injection are based off of the costs for the Kay Baily Hutchinson (KBH) deep well injection site. Costing calculation is split into well construction and pipe construction. From the KBH data, well construction is $16.9 MM. Piping cost assumes an 8 in diameter pipe, and is calculated as:

$$C_{pipe} = 0.28 L_{pipe}$$

The total fixed cost is then calculated by scaling with KBH flow according to:

$$C_{dwi} = (C_{well} + C_{pipe}) \frac{Q_{in}}{Q_{KBH}}^{0.7}$$

This costing function approach and the 0.7 exponent is a generic approach used to make order-of-magnitude cost estimates for processes where only the cost and flow (or capacity) are known from a previous facility that used the same process (Towler & Sinnott, 2021).

Electricity Intensity

Electricity intensity for deep well injection is based off the pump used. The calculation includes:

- Lift height [ft]:

  h

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

- And the influent flow in [gal/min] and [m3/hr]:

  Q_{gpm}, Q_{m3hr}

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{dwi} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{m3hr}}$$

Assumptions

- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

Gavin Towler & Ray Sinnott (ed.) (2021)
Chemical Engineering Design (Third Edition): Principles, Practice and Economics of Plant and Process Design
Chapter 7 - Capital cost estimating, pg 239-278
DOI: 10.1016/B978-0-12-821179-3.00007-8
ISBN: 9780128211793

Deep Well Injection Module

class watertap3.wt_units.deep_well_injection.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity for deep well injection [kWh/m3]

Parameters: **lift_height** (*float*) – Lift height for pump [ft]
Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
Fixed capital cost for deep well injection.

Parameters:
- **unit_params** (*dict*) – Input parameter dictionary from input sheet.
- **lift_height** (*float*) – Lift height for pump [ft]
- **pipe_distance** (*float*) – Piping distance to deep well injection site

Returns: Fixed capital cost for deep well injection [$MM]

Electrodialysis Reversal

Unit Parameters

None.

Capital Costs

Capital costs for electrodialysis reversal are based on those from the Irwin case study.

$$C_{EDR} = 31\frac{Q_{in}}{946}$$

Electricity Intensity

Electricity intensity is a function of TDS [mg/L] into the unit and based off of a regression of data from Baker (2004):

$$E_{EDR} = 0.2534 + 5.149 \times 10^{-4} c_{tds}$$

References

ELECTRICITY

Richard W. Baker (2004)
“Membrane Technology and Applications, Second Edition”
DOI:10.1002/0470020393

Electrodialysis Reversal Module

class watertap3.wt_units.electrodialysis_reversal.**UnitProcess** (*args, **kwds)

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Evaporation Ponds

Evaporation ponds are commonly used to further concentrate membrane brine to reduce the volume needed for disposal.

The generalized approach is as follows:

1. Calculate the evaporation rate based on environmental conditions.
2. Determine area required for evaporation ponds using a mass balance approach.
3. Calculate capital costs based off of area and costing approach selected by user.

Unit Parameters

The evaporation pond model draws from several sources and includes several optional parameters for user input. Further detail on these parameters is provided below:

- `"approach"` - costing approach used for the model (more detail is provided below on each approach):
    - Optional parameter
    - Options are `"wt3"`, `"zld"`, and `"lenntech"`
    - Default approach is `"wt3"` if no input given
    - Must be enclosed in double `" "` or single `' '` quotes
- `"evap_method"` - method used to calculate evaporation rate
    - Optional parameter
    - Two options are `"turc"` and `"jensen"`
    - Defaults to `"jensen"` if no input given
    - Must be enclosed in double `" "` or single `' '` quotes
- `"air_temp"` - air temperature for evaporation rate calculation [C]
    - Optional parameter
    - Default value is 20 deg C
    - Note: Must provide both `"air_temp"` and `"solar_rad"` together or default values for both will be used.
- `"solar_rad"` - incident solar radiation for evaporation rate calculation [mJ/cm2]
    - Optional parameter
    - Default value is 25 mJ/cm2
    - Note: Must provide both `"air_temp"` and `"solar_rad"` together or default values for both will be used.
- `"humidity"` - humidity for use in calculation of ratio to adjust pure water evaporation rate to saline water evaporation rate
    - Optional parameter
    - Default value is 0.5 (i.e. 50% humidity)

- Note: Must provide both "humidity" and "wind_speed" together or default values for both will be used.

- "wind_speed" - wind speed for use in calculation of ratio to adjust pure water evaporation rate [m/s]
  - Optional parameter
  - Default value is 5 m/s
  - Note: Must provide both "humidity" and "wind_speed" together or default values for both will be used.

- "liner_thickness" - thickness of liner used for calculation of cost per acre [mil]
  - Optional parameter
  - Default value is 50 mil
  - Note that 1 mil = 1/1000 inches
  - Note: Must provide "liner_thickness", "land_cost", "land_clearing_cost", and "dike_height" together or default values for all will be used.

- "land_cost" - cost to purchase land for evaporation pond [$/acre]
  - Optional parameter
  - Default value is $5,000/acre
  - Note: Must provide "liner_thickness", "land_cost", "land_clearing_cost", and "dike_height" together or default values for all will be used.

- "land_clearing_cost" - cost to clear land for evaporation pond [$/acre]
  - Optional parameter
  - Default value is $1,000/acre
  - Note: Must provide "liner_thickness", "land_cost", "land_clearing_cost", and "dike_height" together or default values for all will be used.
  - Typical costs for different types of land cover (Bureau of Reclamation, 2006):
    - brush = $1,000/acre
    - sparsley wooded = $2,000/acre
    - medium wooded = $4,000/acre
    - heavily wooded = $7,000/acre

- "dike_height" - height of dikes for evaporation pond [ft]
  - Default value is 8 ft
  - Typical dike heights are 4-12 ft (from Bureau of Reclamation reference)
  - Note: Must provide "liner_thickness", "land_cost", "land_clearing_cost", and "dike_height" together or default values for all will be used.

Evaporation Rate Calculation

The evaporation rate is R is dependent on site specific meteorological conditions and the salinity of the water. Salintiy has the effect of lowering the evaporation rate, and because evaporation ponds are commonlny used to concentrate brine streams, an evaporation rate calculated for pure water must be adjusted downward.

WaterTAP3 uses one of two regressions from each of the two references below to estimate the evaporation rate of pure water under the given meteorological conditions. Both are functions of air temperature T and solar irradiance J. For Jensen & Haise (1963) [mm/day]:

$$R_{pure} = R_{j\&h} = 0.41J(0.025T + 0.078)$$

And for Turc (1961) [mmday]:

$$R_{pure} = R_{turc} = \frac{0.313T(J + 2.1)}{T + 15}$$

In WaterTAP3, the water in the pond is assumed to be saline. The evaporation rate of saline water can be estimated to be 70% that of pure water (WateReuse Foundation, 2008). Thus, this calculated evaporation rate is multiplied by 0.7 to arrive at the estimated evaporation rate for saline water:

$$R_{saline} = 0.7R_{pure}$$

Pond Area Calculation

For mass balance purposes in WaterTAP3, the flow of evaporated water is the considered to be the flow out of the unit. To accomodate a given water recovery, the area of the pond is calculated as:

$$A_{pond} = \frac{Q_{out}}{R_{saline}}$$

Capital Costs

The user can choose one of three costing approaches for evaporation ponds in WaterTAP3 that can be provided as an option in `unit_params` under `"approach"`:

1. `"wt3"` - default approach if the user does not provide one. Incorporates an adjusted pond area and more indepth costing function. Based on Bureau of Reclamation reference below.
2. `"zld"` - only considers area and assumes $0.3M/acre. Based on WateReuse reference below.
3. `"lenntech"` - capital cost determined purely from flow. Based on Lenntech reference below.

WT3 Approach:

The WT3 approach is the default approach and uses a regression for total pond area from the Bureau of Reclamation reference below. After calculation of the required pond area based on flow above, if this approach is used the pond area is adjusted upwards to inorporate the additional area needed for dikes:

$$A_{adj} = 1.2(A_{pond})(1 + 0.155\frac{H_{dike}}{\sqrt{A_{pond}}})$$

Then, the cost per acre [$/acre] is determined that incorporates `"liner_thickness"`, `"land_cost"`, `"land_clearing_cost"`, and `"dike_height"`:

$$C_{acre} = 5406 + 465(z_{liner}) + 1.07(C_{land}) + 0.931(C_{clear}) + 217.5(H_{dike})$$

Thus, using this approach capital costs for evaporation ponds are calculated as:

$$C_{evap} = A_{adj}C_{acre}$$

ZLD Approach:

The ZLD approach is named from the WateReuse document it was adapted from. Using this approach, the unadjusted pond area is used. The cost per acre is assumed to be $0.3MM. Thus, the capital costs are calculated as:

$$C_{evap} = A_{pond} \times 0.3$$

Lenntech Approach:

This approach is based entirely on flow in [m3/d] to the evaporation pond and does not include the calculation for evaporation pond area. It assumes an evaporation rate of 1 m/yr:

$$C_{evap} = 0.031 Q_{in}^{0.7613}$$

Note that while the reference mentions salt concentrations, land and earthwork costs, and liner costs, it is unclear how these are incorporated into the cost curve above.

Electricity Cost

WaterTAP3 does not include any electricity intensity for evaporation ponds.

References

EVAPORATION RATE

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“Estimating evapotranspiration from solar radiation.”
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WateReuse Foundation (2008)
Mickley, Michael C.
“Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities”
ISBN: 978-1-934183-08-3

Lenntech.com
https://www.lenntech.com/Data-sheets/Brine-Evaporation-Ponds.pdf

Evaporation Pond Module

class `watertap3.wt_units.evaporation_pond.`**`UnitProcess`** (*args, **kwds)

`elect` **()**

WaterTAP3 has no electricity intensity associated with evaporation ponds.

evaporation_rate (unit_params**,** t**)**
Calculation of evaporation rate [gpm/acre]

Parameters:
- **unit_params** (*dict*) – Input dictionary from input sheet.
- **t** (*int*) – Time indexing variable to use in Var()
- **evap_method** (*str*) – Evaporation rate method
- **humidity** (*float*) – Humidity expressed as decimal for evaporation rate calculation
- **wind_speed** (*float*) – Wind speed for evaporation rate calculation [m/s]
- **air_temp** (*float*) – Air temperature for evaporation rate calculation [C]
- **solar_rad** (*float*) – Incident solar radiation for evaporation rate calculation [mJ/m2]

Returns:

evaporation_rate_regress (t**)**
NOTE: THIS FUNCTION IS NOT USED IN THE CURRENT RELEASE OF WaterTAP3
Calculates evaporation rate based on air temperature, TDS in, humidity, and wind speed.

fixed_cap (unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary.
Evaporation ponds can have many unit_params
EXAMPLE: {‘approach’: ‘wt3’, ‘area’: 3500, ‘humidity’: 0.75, ‘wind_speed’: 10}

Parameters:
- **unit_params** (*dict*) – Input parameter dictionary from input sheet.
- **liner_thickness** (*float*) – Liner thickness [mil]
- **land_cost** (*float*) – Cost of land for evaporation pond [$/acre]
- **land_clearing_cost** (*float*) – Cost to clear land for evaporation pond [$/acre]
- **dike_height** (*float*) – Height of dikes [ft]

Returns: Fixed capital cost for evaporation ponds [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Ferric Chloride Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]

    - Required parameter

Capital Costs

The ferric chloride solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single ferric chloride addition unit, *a* = 34153 and *b* = 0.319. The full cost equation in WaterTAP3 is:

$$C_{ferric} = 34153S^{0.319}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.13 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{ferric} = Q_{in}D_{ferric}$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

    $S = \frac{M_{ferric}}{\rho_{ferric}X_{ferric}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{ferric} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1460

- Ratio in solution = 42%
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Ferric Chloride Addition Module

class watertap3.wt_units.ferric_chloride_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}
Fixed capital for ferric chloride addition is a function of ferric dose, ferric solution flow, and the number of units.

Returns: Ferric addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters:
- **solution_density** (*float*) – Solution density [kg/m3]
- **ratio_in_solution** (*float*) – Ratio of chemical in solution

Returns: Ferric solution flow [gal/day]

Filter Press

The Filter Press module in WaterTAP3 can represent capital and electricity costs for both a belt filter press and pressure filter press.

Unit Parameters

There are three optional unit parameters for the filter press module:

- `"type"` - the type of filter press to be modeled:
    - Optional parameter
    - Options are `"belt"` or `"pressure"`
    - Default type is `"belt"` if no input provided
- `"hours_per_day_operation"` - hours per day the filter press is in operation [hr]:
    - Optional parameter
    - Default is 24 hours if no input provided
- `"cycle_time"` - cycle time duration [hours]:
    - Optional parameter
    - Default is 3 hours if no input provided

Capital Costs

The capital costs are a function of the flow into the filter press [gal/hr] (McGivney & Kawamura (2008)).

For belt filter press:

$$C_{belt} = 146.29 * Q + 433972$$

For pressure filter press:

$$C_{pressure} = 102794 Q^{0.4216}$$

Electricity Intensity

The annual energy use data provided in Wang, Shammas, and Hung (2007) is a function of the filter press capacity (or volume) and is fit to a power curve:

$$E = aV^{b}$$

Filter press capacity (or volume) [ft3] is the volume of solids the filter press must handle per cycle:

$$V_{fp} = Q/n$$

Where ‘n’ is the number of cycles per day and is the hours per day of operation [hr/day] divided by the cycle time [hr]:

$$n = \frac{t_{op}}{t_{cycle}}$$

Then, the electricity intensity [kWh/m3] is calculated as the annual energy use [kWh/yr] divided by the annual sludge flow [m3/yr] into the filter press.

For a belt filter press:

$$E_{fp} = \frac{16.285 V_{fp}^{1.2434}}{Q}$$

For a pressure filter press:

$$E_{fp} = \frac{16.612 V_{fp}^{1.2195}}{Q}$$

Assumptions

- Percent influent solids = 6%

References

CAPITAL

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

ELECTRICITY

Lawrence K. Wang, Nazih K. Shammas, Yung-Tse Hung (Ed.) (2007)
Biosolids Treatment Processes
Chap. 17 “Belt Filter Press” & Chap. 18 “Pressure Filtration”
DOI: 10.1007/978-1-59259-996-7
eBook ISBN: 978-1-59259-996-7

Filter Press Module

class `watertap3.wt_units.filter_press.`**`UnitProcess`** (*args, **kwds)

`elect` **()**

Returns:

`fixed_cap` **()**

Returns:

Fixed Bed Gravity Basin

The fixed bed gravity basin unit in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model. These models each have some "standard designs" that make default assumptions and span a range of flows 0.03 MGD to 75 MGD (USEPA (2019)).

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs with the fixed bed gravity basin option. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve. Then *a* and *b* are used with the flow for the model to determine capital and electricity intensity.

Unit Parameters

None.

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{fbgb} = aQ_{in}^{b}$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine electricity intensity:

$$E_{fbgb} = aQ_{in}^{b}$$

Chemical Use

The WBS EPA model includes costs for acetic acid, phosphoric acid, iron chloride, activated carbon, sand, and anthracite. The average is taken for the range of flows and assumed to be the "dose" for the particular chemical/material.

References

US Environmental Protection Agency (2019)
"Work Breakdown Structure-Based Cost Model for Biological Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-07/documents/wbs-biotreat-documentation-june-2019.pdf
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Fixed Bed Gravity Basin Module

class `watertap3.wt_units.fixed_bed_gravity_basin.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for fixed bed gravity basin [kWh/m3] :return:

`fixed_cap` **()**

Returns: Fixed capital for fixed bed gravity basin [$MM]

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Fixed Bed Pressure Vessel

The fixed bed gravity basin unit in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model. These models each have some "standard designs" that make default assumptions and span a range of flows 0.03 MGD to 75 MGD (USEPA (2019)).

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs with the fixed bed pressure vessel option. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve. Then *a* and *b* are used with the flow for the model to determine capital and electricity intensity.

Unit Parameters

None

Capital Costs

The `cap_total` column is read in from the `cost_curves.csv` and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{fbpv} = aQ_{in}^{b}$$

Electricity Intensity

The `electricity_intensity` column is read in from the `cost_curves.csv` and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine electricity intensity:

$$E_{fbpv} = aQ_{in}^{b}$$

Chemical Use

The WBS EPA model includes costs for acetic acid, phosphoric acid, iron chloride, activated carbon, sand, and anthracite. The average is taken for the range of flows and assumed to be the "dose" for the particular chemical/material.

References

US Environmental Protection Agency (2019)
"Work Breakdown Structure-Based Cost Model for Biological Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-07/documents/wbs-biotreat-documentation-june-2019.pdf
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Fixed Bed Pressure Vessel Module

class `watertap3.wt_units.fixed_bed_pressure_vessel.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for fixed bed pressure vessel [kWh/m3] :return:

`fixed_cap` **()**

Returns: Fixed capital for fixed bed pressure vessel [$MM]

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

GAC - Gravity

The gravity GAC unit in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model. These models each have some "standard designs" that make default assumptions and span a range of flows 0.03 MGD to 75 MGD (USEPA (2019)).

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs with the gravity GAC option. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve. Then *a* and *b* are used with the flow for the model to determine capital and electricity intensity.

Unit Parameters

Anion exchange has one parameter:

- `"ebct"` - empty bed contact time for the unit [min]:
    - Required parameter
    - There are different costing data for 0-60 min and >60 min

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on user-defined EBCT and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{gac} = aQ_{in}^{b}$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` based on user-defined EBCT and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine electricity intensity:

$$E_{gac} = aQ_{in}^{b}$$

Chemical Use

The WBS EPA model includes costs for activated carbon. The average is taken for the range of flows and assumed to be the "dose" for the particular chemical/material.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Granular Activated Carbon Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-03/documents/wbs-gac-documentation-dec-2017_v2.pdf
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

GAC - Gravity Module

class `watertap3.wt_units.gac_gravity.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity gravity GAC [kWh/m3] :return:

fixed_cap (unit_params**)**

Returns: Fixed capital for gravity GAC [$MM]

get_costing (unit_params=None**,** year=None**)**

Initialize the unit in WaterTAP3.

GAC - Pressure Vessel

The GAC pressure vessel in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model. The WBS EPA models each have some "standard designs" that make default assumptions (USEPA (2019)) and span a range of flows 0.03 MGD to 75 MGD.

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs with the fixed bed gravity basin option. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve. Then *a* and *b* are used with the flow for the model.

Unit Parameters

Anion exchange has one parameter:

- `"ebct"` - empty bed contact time for the unit [min]:
    - Required parameter
    - There are different costing data for 0-60 min and >60 min

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on user-defined EBCT and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{gac} = aQ_{in}^{b}$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` based on user-defined EBCT and is fit to a power curve. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine electricity intensity:

$$E_{gac} = aQ_{in}^{b}$$

Chemical Use

The WBS EPA model includes costs for activated carbon. The average is taken for the range of flows and assumed to be the "dose" for the particular chemical/material.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Granular Activated Carbon Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-03/documents/wbs-gac-documentation-dec-2017_v2.pdf
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

GAC - Pressure Vessel Module

class `watertap3.wt_units.gac_pressure_vessel.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for pressure vessel GAC [kWh/m3] :return:

`fixed_cap` **(**unit_params**)**

Returns: Fixed capital for pressure vessel GAC [$MM]

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Heap Leaching

Heap leaching is the process of collecting the leached solution irrigated over a stack of metal-bearing ores. |

Unit Parameters

There are two parameters:

- `"mining_capacity"` - mining capacity for the mine [tonnes/day]
    - Optional parameter
    - Default value is 922 tonnes/day
    - Must be provided with `"ore_heap_soln"` or default values for both will be used.
- `"ore_heap_soln"` - volume of leach solution needed per mass ore [gal/tonne]
    - Optional parameter
    - Default value is 500 gal/tonne
    - Must be provided with `"mining_capacity"` or default values for both will be used.

Capital Costs

Capital costs for heap leaching and other associated mine units (i.e. Solution Distribution and Recovery Plant, Agglomeration and Stacking) are derived from Table 3 in Kappes (2002). The costing components explicitly calculated for these units via regressed data from this table are (associated WaterTAP3 unit in parentheses):

- Mining equipment (Heap Leaching)
- Mine development (Heap Leaching)
- Crushing plant (Heap Leaching)
- Leaching pads/ponds (Heap Leaching)
- Agglomeration/stacking system (Agglomeration and Stacking)
- Solution distribution and recovery plant (Solution Distribution and Recovery Plant)

The costs from this table that are estimated via different method below are:

- Infrastructure (power, water, access roads, site office, service facilities)
- Owner’s preproduction cost
- Engineering, procurement, construction management
- Import duties
- Equipment and materials transport
- Initial operating supplies

Note that laboratory costs and working capital costs from this table are accounted for elsewhere in WaterTAP3 and so are excluded from the unit process calculations.

Capital costs for heap leaching are a function of the mining equipment, mine development, the crushing plant, and the leaching pads/ponds. Each of these are a function of the mining capacity X [tonnes/day]. Cost curves for these components were derived from data for mining capacities of 3,000 tonnes/day and 15,000 tonnes/day from Table 3 in Kappes (2002):

$$C_{equip} = 0.00124X^{0.93454}$$

$$C_{devel} = 0.01908X^{0.43068}$$

$$C_{crush} = 0.0058X^{0.6651}$$

$$C_{leach} = 0.0005X^{0.94819}$$

To account for the other tabulated costing components in Table 3, WaterTAP3 calculates the fraction *f* that the other costs are of the component costs (i.e. other costs / component costs). The other costs fraction *f* are determined from a regression of the total cost in Table 3 minus the sum of the heap leaching costs (calculated above) vs. the mining capacities in that table (3,000 and 15,000 tonnes/day):

$$f = 0.3012X^{0.1119}$$

This fraction is multiplied by the sum of the component costs (calculated above) and added to that sum. This is the costing basis for Heap Leaching:

$$C_{basis} = (C_{equip} + C_{devel} + C_{crush} + C_{leach})(1 + f)$$

To create a cost curve based on unit flow, WaterTAP3 scales the unit flow to 73 m3/hr (derived from the initial heap leaching case study used to develop WaterTAP3) and creates an exponent *b* from:

$$b = \frac{0.935C_{equip} + 0.431C_{devel} + 0.665C_{crush} + 0.948C_{leach}}{C_{equip} + C_{devel} + C_{crush} + C_{leach}}$$

Note that the coefficients in the numerator of the above equation are the exponents for the cost curves for each costing component.

And then the final capital costing curve for heap leaching unit is:

$$C_{heap} = \frac{Q_{in}}{73} C_{basis}^{b}$$

Operating Costs

The operating costs [$/year] for heap leaching are derived with cost curves regressed from data in Table 5 of Kappes (2002). Included for heap leaching in WaterTAP3 are operational costs relating to:

- Mining equipment
- Crushing plant
- Leaching pads/ponds

These cost curves are:

$$C_{mining} = 22.54816X^{0.74807}$$
$$C_{crush} = 4.466X^{0.8794}$$
$$C_{leach} = 6.34727X^{0.68261}$$

The total operating cost is the sum of these components:

$$C_{op} = C_{mining} + C_{crush} + C_{leach}$$

Electricity Intensity

There is no electricity intensity associated with heap leaching.

References

Kappes, D.W. “Precious Metal Heap Leach Design and Practice” (2002)
in: *Mineral processing plant design, practice, and control*
pg. 1606-1630, ISBN: 0873352238

http://ore-max.com/pdfs/resources/precious_metal_heap_leach_design_and_practice.pdf

Heap Leaching Module

class watertap3.wt_units.heap_leaching.**UnitProcess** (*args, **kwds)

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Hydrochloric Acid Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]
    - Required parameter

Capital Costs

The hydrochloric acid solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single hydrochloric acid addition unit, *a* = 900.97 and *b* = 0.6179. The full cost equation in WaterTAP3 is:

$$C_{HCl} = 900.97S^{0.6179}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{HCl} = Q_{in}D_{HCl}$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

    $S = \frac{M_{HCl}}{\rho_{HCl}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{HCl} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1490

- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Hydrochloric Acid Addition Module

class watertap3.wt_units.hydrochloric_acid_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'dose': 10}

Returns: HCl addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]
Returns: HCl solution flow [gal/day]

Iron & Manganese Removal

The Fe/Mn removal unit in WaterTAP3 is based off of the dual media filtration schematic in the Lenntech reference using costing data in McGivney & Kawamura (2008).

Unit Parameters

None

Capital Costs

The coagulation/flocculation unit in WaterTAP3 includes costing for filtration media, backwash system, and air blower.

$$C_{Fe/Mn} = (C_{filt} + C_{bw} + nC_{blow})\frac{Q_{in}}{4732}^{0.7}$$

The 0.7 exponent is a generic exponent used to make order-of-magnitude cost estimates for processes where only the cost and flow (or capacity) are known from a previous facility that used the same process (Towler & Sinnott, 2021). | Filtration capital is a function of media surface area and calculated with:

$$C_{filt} = 21377 + 38.319A$$

Backwash capital is also a function of media surface area:

$$C_{bw} = 92947 + 292.44A$$

The blower capital is assumed.

Assumptions

There are six units:

$$n = 6$$

The filter surface area is 6243 ft2:

$$A = 6243$$

The air/water ratio in the blower is 0.001 [v/v]:

$$f = 0.001$$

The capital for the air blower is $100,000:

$$C_{blow} = 100000$$

Electricity Intensity

The total electricity intensity for Fe/Mn removal is from the blower [kWh/m3]:

$$E_{Fe/Mn} = \frac{p_{blow}}{Q_{in}}$$

Where blower power is calculated with [hp]:

$$p_{rm} = 147.8q_{air}$$

And the air flow rate is [m3/hr]:

$$q_{air} = Q_{in} r$$

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Gavin Towler & Ray Sinnott (ed.) (2021)
Chemical Engineering Design (Third Edition): Principles, Practice and Economics of Plant and Process Design
Chapter 7 - Capital cost estimating, pg 239-278
DOI: 10.1016/B978-0-12-821179-3.00007-8
ISBN: 9780128211793

Schema of an iron removal system
https://www.lenntech.com/schema-of-an-iron-removal-system.htm

Iron & Manganese Removal Module

class `watertap3.wt_units.iron_and_manganese_removal.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Landfill

Unit Basics

This unit is a terminal unit in WaterTAP3 and represents the cost of sending residual solids to landfill.

Unit Parameters

None.

Capital Costs

Landfill costs are a function of mass flow into the unit:

$$C_{lf} = \frac{M_{in}}{100000}^{0.7}$$

The 0.7 exponent is a generic exponent used to make order-of-magnitude cost estimates for processes where only the cost and flow (or capacity) are known from a previous facility that used the same process (Towler & Sinnott, 2021). | The mass flow is calculated by first calculating the total concentration flowing into the unit:

$$C_{in} = \sum_{i}^{n} c_i$$

Then, we estimate the density of the solution [kg/m3]:

$$\rho_{in} = 0.6312(C_{in}) + 997.86$$

Mass flow [kg/hr] is determined with:

$$M_{in} = \rho_{in} Q_{in}$$

Electricity Intensity

There are no electricity costs associated with landfill in WaterTAP3.

References

Gavin Towler & Ray Sinnott (ed.) (2021)
Chemical Engineering Design (Third Edition): Principles, Practice and Economics of Plant and Process Design
Chapter 7 - Capital cost estimating, pg 239-278
DOI: 10.1016/B978-0-12-821179-3.00007-8
ISBN: 9780128211793

Landfill Module

class `watertap3.wt_units.landfill.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Landfill ZLD

Unit Basics

This unit is a terminal unit in WaterTAP3 and represents the cost of sending residual solids to landfill.

Unit Parameters

None.

Capital Costs

Landfill ZLD costs are a function of mass flow into the unit:

$$C_{lf} = \frac{M_{in}}{302096}^{0.7}$$

The 0.7 exponent is a generic exponent used to make order-of-magnitude cost estimates for processes where only the cost and flow (or capacity) are known from a previous facility that used the same process (Towler & Sinnott, 2021). | The mass flow is calculated by first calculating the total concentration flowing into the unit:

$$C_{in} = \sum_{i}^{n} c_i$$

Then, we estimate the density of the solution [kg/m3]:

$$\rho_{in} = 0.6312(C_{in}) + 997.86$$

Mass flow [kg/hr] is determined with:

$$M_{in} = \rho_{in} Q_{in}$$

Electricity Intensity

There are no electricity costs associated with landfill ZLD in WaterTAP3.

References

Mickley, Michael C. (2008)
“Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities”
WateReuse Foundation
ISBN: 978-1-934183-08-3

Gavin Towler & Ray Sinnott (ed.) (2021)
Chemical Engineering Design (Third Edition): Principles, Practice and Economics of Plant and Process Design
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Landfill ZLD Module

class `watertap3.wt_units.landfill_zld.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Lime Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

- `"lime"` - dose of lime [mg/L]
    - Required parameter

Capital Costs

The lime solution mass flow *M* [lb/day] is used in a cost curve of the general form:

$$C = aM^b$$

For a single lime addition unit, *a* = 16972 and *b* = 0.5435. The full cost equation in WaterTAP3 is:

$$C_{lime} = 16972S^{0.5435}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.9 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

  h

- The mass flow rate [kg/hr] of the solution necessary to achieve the desired dose:

  $$M_{lime} = Q_{in}D_{lime}$$

- The volumetric flow *S* [m3/hr] of the chemical solution, which incorporates the solution density [kg/m3]:

  $$S = \frac{M_{lime}}{\rho_{lime}}$$

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{lime} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1250
- Lift height [ft] = 100

- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Lime Addition Module

class watertap3.wt_units.lime_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'lime': 10}
Fixed capital for lime addition is a function of lime dose, lime solution flow, and the number of units.

Parameters: **lime** (*float*) – Lime dose [mg/L]
Returns: Lime addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]
Returns: Lime solution vol. flow [gal/day], Lime solution mass flow [lb/day]

Lime Softening

Unit Parameters

There is one unit parameter:

- `"lime"` - lime dose for unit [mg/L]:
    - Required parameter

Capital Costs

The capital costs are a function of flow [m3/hr] with cost curve parameters from the Minnesota Rural Water Association.

$$C_{lime} = 0.0704 Q_{in}^{0.7306}$$

Electricity Intensity

Electricity intensity for lime softening is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

  h

- The mass flow rate [kg/hr] of the solution necessary to achieve the desired dose:

  $M_{lime} = Q_{in} D_{lime}$

- The volumetric flow S [m3/hr] of the chemical solution, which incorporates the solution density [kg/m3]:

  $S = \frac{M_{lime}}{\rho_{lime}}$

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{lime} = \frac{0.746 S h}{3960 \eta_{pump} \eta_{motor} Q_{in}}$$

Assumptions

- Solution density [kg/m3] = 1250
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

References

Minnesota Rural Water Association, Chapter 16 Lime Softening
https://www.mrwa.com/WaterWorksMnl/Chapter%2016%20Lime%20Softening.pdf

Lime Softening Module

class watertap3.wt_units.lime_softening.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity for chemical additions is a function of lift height, pump efficiency, and motor efficiency.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘lime’: 10}
Fixed capital for lime addition is a function of lime dose, lime solution flow, and the number of units.

Parameters: **lime** (*float*) – Lime dose [mg/L]

Returns: Lime addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Determine alum solution flow rate in gal / day

Returns: Lime solution flow [gal/day]

Media Filtration

Unit Parameters

None

Capital Costs

Capital costs for media filtration includes the cost of the filter and the cost of the backwash system (McGivney & Kawamura (2008)).

$$C_{mf} = C_{filter} + C_{bw}$$

The cost of the filter is a function of the surface area and the number of units:

$$C_{filter} = (21377 + 38.319A)n$$

With the filter surface area calculated with the assumed filtration rate [ft2]:

$$A = \frac{Q_{in}}{v}$$

The cost of the backwash system is also a function of filter surface area:

$$C_{bw} = 92947 + 292.44A$$

Assumptions

There are six units:

$$n = 6$$

The filtration rate is 10 m/hr:

$$v = 10$$

Electricity Intensity

Electricity intensity is fixed at 0.00015 kWh/m3 from Bukhary et al. (2019).

References

CAPITAL

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

ELECTRICITY

Bukhary, S., et al. (2019).
“An Analysis of Energy Consumption and the Use of Renewables for a Small Drinking Water Treatment Plant.”
Water 12(1).

Media Filtration Module

class `watertap3.wt_units.media_filtration.`**`UnitProcess`** (*args, **kwds)

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Microfiltration

Unit Parameters

None

Capital Costs

Capital costs for microfiltration is based entirely on flow [MGD] from Table 3.20 in the Texas Water Board reference:

$$C_{MF} = 2.5Q_{in}$$

Electricity Intensity

Electricity intensity is fixed at 0.18 kWh/m3 from Plappally & Lienhard (2012).

References

CAPITAL

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

Plappally, A. K. and J. H. Lienhard V (2012).
"Energy requirements for water production, treatment, end use, reclamation, and disposal."
Renewable and Sustainable Energy Reviews 16(7): 4818-4848.

Microfiltation Module

class `watertap3.wt_units.microfiltration.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Multi-Stage Bubble Aeration

The multi-stage bubble aeration unit in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model. These models each have some "standard designs" that make default assumptions and span a range of flows 0.03 MGD to 75 MGD (USEPA (2019)).

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve. Then *a* and *b* are used with the flow for the model to determine capital and electricity intensity.

Unit Parameters

None

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{msba} = aQ_{in}^{b}$$

Electricity Intensity

The `electricity_flow` column is read in from the `epa_cost_curves.csv` based on influent TDS and is fit to the power curve described above. Then *a* and *b* from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$E_{msba} = aQ_{in}^{b}$$

Chemical Use

The WBS EPA model does not include any chemical/material costs for multi-stage bubble aeration.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Multi-Stage Bubble Aeration Drinking Water Treatment"
https://www.epa.gov/sites/production/files/2019-03/documents/wbs-msba-documentation-dec-2017_v2.pdf
https://www.epa.gov/sdwa/drinking-water-treatment-technology-unit-cost-models

Multi-Stage Bubble Aeration Module

class `watertap3.wt_units.multi_stage_bubble_aeration.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for multi-stage bubble aeration [kWh/m3] :return:

`fixed_cap` **()**

Returns: Fixed capital for multi-stage bubble aeration [$MM]

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Municipal Drinking (Distribution)

This unit is a terminal unit in WaterTAP3 and represents the initial cost to get product water to the distribution system.

Unit Parameters

None

Capital Costs

The capital costs are a function of flow [MGD]:

$$C_{md} = 0.0403 Q_{in}^{0.8657}$$

Electricity Intensity

Electricity intensity for municipal drinking is based off the pump used. The calculation includes:

- Lift height [ft]:

  h

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

- And the influent flow in [gal/min] and [m3/hr]:

  Q_{gpm}, Q_{m3hr}

Then the electricity intensity is calculated as:

$$E_{bw} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{m3hr}}$$

Assumptions

- Lift height [ft] = 300
- Pump efficiency = 0.9
- Motor efficiency = 0.9

References

Voutchkov, N. (2018).
Desalination Project Cost Estimating and Management.
https://doi.org/10.1201/9781351242738

Municipal Drinking (Distribution) Module

class `watertap3.wt_units.municipal_drinking.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Ozone + AOP

The Ozone unit in WaterTAP3 is used to calculate costs for both Ozone and Ozone+AOP systems.

Unit Parameters

Unit parameters are read in from the `unit_params` dictionary given in the input sheet.

- `"aop"` - boolean to indicate if the unit includes AOP costs:
    - Required parameter
    - If `True`, oxidant costs are included
    - If `False`, oxidant costs are excluded
- `"contact_time"` - contact time with ozone [min]
    - Required parameter
- `"ct"` - Concentration * time (Ct) target [mg/(L*min)]
    - Required parameter
- `"mass_transfer"` - mass transfer efficiency coefficient for ozone contactor
    - Required parameter
- `"chemical_name"` - oxidant chemical name
    - Required parameter if `aop = True`
    - Must match exactly the chemical name in `catalyst_chemicals.csv`

Capital Costs

The Ozone/AOP unit in WaterTAP3 is used for both Ozone only units and Ozone+AOP units. For this reason costs are broken up between the ozone system and the oxidant injection system.

Ozone Capital Costs

Ozone capital costs in WaterTAP3 are a function of the ozone contact time, Ct, ozone mass transfer, ozone dose, TOC concentration, flow in, and the ozone/TOC ratio.

TOC concentration and flow in are taken from the model. Contact time, mass transfer efficiency, and Ct are taken from user input. Ozone demand is calculated from Texas Water Development Board (2016):

$$D_{O3} = \frac{t_{O3} c_{toc} Ct}{\eta_{O3}}$$

Ozone dose is then used in a regression dervied from data found in Table 3.24 from Texas Water Development Board (2016).

Oxidant Capital Costs

The unit can accept any chemical name and dose, but the cost curve used was developed specifically for Hydrogen Peroxide in Texas Water Development Board (2016):

$$C_{ox} = 1228 S_{ox}^{0.2277}$$

Oxidant costs are calculated are based off the oxidant solution flow [lb/day]:

$$S_{ox} = Q_{in} D_{ox}$$

Where the oxidant dose is calculated with [kg/m3]:

$$D_{ox} = 0.5 f c_{toc}$$

And the ozone/TOC ratio *f* is calculated with:

$$f = 1 + \frac{t_{O3} Ct}{c_{toc}}$$

Electricity Intensity

Electricity intensity is a function of the ozone flow [lb/day] and water flow into unit [m3/hr] from Mundy et al. (2018):

$$E_{O3} = 5 \frac{Q_{O3}}{Q_{in}}$$

References

COSTING

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

Mundy, B., et al. (2018).
"A Review of Ozone Systems Costs for Municipal Applications. Report by the Municipal Committee – IOA Pan American Group."
Ozone: Science & Engineering 40(4): 266-274.

Ozone + AOP Module

class `watertap3.wt_units.ozone_aop.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
Electricity intensity for Ozone/Ozone AOP unit.

Parameters: **ozone_flow** (*float*) – Flow of ozone from ozone generator [lb/day]
Returns: Ozone/Ozone AOP electricity intenstiy [kWh/m3]

`fixed_cap` **(**unit_params**)**
Fixed capital for Ozone/Ozone AOP unit.

Parameters:

- **unit_params** (*dict*) – Input parameter dictionary from input sheet
- **toc_in** (*float*) – TOC concentration into unit [mg/L]
- **aop** (*bool*) – Boolean to indicate if unit is AOP or not.
- **contact_time** (*float*) – Ozone contact time [min]
- **ct** (*float*) – Concentration * time (Ct) target [mg/(L*min)]
- **mass_transfer** (*float*) – Mass transfer coefficient
- **chemical_name** (*str*) – Name of oxidant used if unit is AOP

Returns: Fixed capital cost for Ozone/Ozone AOP [$MM]

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

`solution_vol_flow` **()**
Determine oxidant solution flow rate [gal/day]

Returns: Oxidant solution flow [gal/day]

Packed Tower Aeration

The packed tower aeration model in WaterTAP3 is based off of a regression of several runs using EPA's Work Breakdown Structure-Based (WBS EPA) model (see reference). These models incorporate several aspects of cost of the treatment process, including treatment, monitoring, and administrative costs. Both capital cost and electricity intensity are based entirely on volumetric flow, but are assumed to incorporate these costing aspects of the EPA model.

The WBS EPA models each have some "standard designs" that make default assumptions (see EPA documentation) and span a range of flows 0.03 MGD to 75 MGD. Radon removal (called `radon_rem` in WaterTAP3) also affects cost. The EPA model outputs several costing parameters, including total capital cost.

The approach for the WT3 model is to regress the total capital cost output from the EPA model vs. flow for each of the EPA model standard designs using radon removal of 90% and 99%. The different capital costs for each of these model runs is determined from the radon removal percentage user input. A similar approach is taken to determine electricity intensity.

Both sets of data are fit to a power curve:

$$Y = aQ^b$$

Where Q is the flows for the standard design EPA models. Then a and b are used with the flow in for the particular case study.

Unit Parameters

There is one unit parameter:

- `"radon_rem"` - Radon removal for unit [%]
    - Required parameter

Capital Costs

The `cap_total` column is read in from the `epa_cost_curves.csv` based on radon removal and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$C_{ax} = aQ_{in}^b$$

Electricity Intensity

The `electricity_intensity` column is read in from the `epa_cost_curves.csv` based on radon removal and is fit to the power curve described above. Then a and b from that regression is used with the unit flow [m3/hr] to determine capital costs:

$$E_{ax} = aQ_{in}^b$$

Chemical Use

There is no chemical use for the packed tower aeration model in WaterTAP3.

References

US Environmental Protection Agency (2017)
"Work Breakdown Structure-Based Cost Model for Packed Tower Aeration Drinking Water Treatment"
https://www.epa.gov/sites/default/files/2019-03/documents/wbs-pta-documentation-dec-2017_v2.pdf

Packed Tower Aeration Module

class `watertap3.wt_units.packed_tower_aeration.`**`UnitProcess`** (*args, **kwds)

elect ()
Electricity intensity for packed tower aeration [kWh/m3] :return:

fixed_cap (unit_params**)**

Returns: Fixed capital for packed tower aeration [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Reverse Osmosis

The capital cost, O&M costs, electricity consumption, TDS removal, and water recovery of the reverse osmosis unit model are based on a basic representation of the physical performance of the process. This includes calculations of osmostic pressure and mass balance across the membrane. The feed pressure (i.e. pump power required) and membrane area are estimated based on optimizing for LCOW, unless specified otherwise. All other variables in the reverse osmosis model have default assumptions, provided below, that factor into calculating the water recovery, TDS removal, pure water flux, and osmotic pressure.

Unit Parameters

The user only has to specify whether or not to include an energy recovery device (ERD).

- `"erd"` - whether or not to include an ERD
    - Required parameter
    - Options are `"yes"` or `"no"`

Unit Constraints

The reverse osmosis unit in WaterTAP3 is broken up into a feed, permeate, and retentate IDAES `Block()` to track the different mass, flow, and pressure changes for each stream.

Mass and Pressure Constraints

The unit only uses the TDS concentration into the unit to estimate the total concentration of mass going into each reverse osmosis unit.

Thus, for each block (feed, permeate, retentate), some or all of the following mass and/or energy balance equations apply.

The total concentration of TDS flowing into the unit is [kg/m3]:

$$c_{tot} = 0.6312 c_{tds} + 997.86$$

The mass concentration of water into the block is [kg/m3]:

$$c_w = c_{tot} - c_{tds}$$

The mass flow of water into the block is [kg/s]:

$$M_w = c_w Q_{in}$$

The mass flow of TDS into the block is [kg/s]:

$$M_{TDS} = c_{TDS} Q_{in}$$

The mass fraction of TDS into the block is:

$$m_{TDS} = \frac{M_{TDS}}{M_w + M_{TDS}}$$

The mass fraction of water into the block is:

$$m_w = \frac{M_w}{M_w + M_{TDS}}$$

The overall mass balance around water flow is:

$$M_{w,f} = M_{w,p} + M_{w,r}$$

And the overall mass balance around TDS is:

$$M_{tds,f} = M_{tds,p} + M_{tds,r}$$

Feed Block

The osmotic coefficient is calculated according to (Bartholomew & Mauter (2019)):

$$\sigma = 4.92x_{TDS}^2 + 0.0889m_{TDS} + 0.918$$

Then the osmotic pressure [bar] is calculated as:

$$P_{osm} = \frac{8.45 \times 10^7 \sigma m_{TDS}}{1 - m_{TDS}}$$

The flux is calculated from the feed stream as:

$$J_w = \rho_w K_w (P_{feed} - P_{atm} - 0.5P_d) - (0.5(P_{osm,f} + P_{osm,r}))$$

The pressure drop is assumed to be 3 bar.

Permeate Stream

The equation for mass into permeate is different than for feed or retentate streams (Bartholomew & Mauter (2019)):

$$c_{tot,p} = 756c_{tds} \times 10^{-6} + 995$$

The concentration coming out of the unit is:

$$c_{tds,out} = c_{tot,p} m_{tds,p}$$

The mass flow of water is determined from the membrane area and pure water flux:

$$M_{w,p} = J_w A$$

The mass flow of TDS is determined from the membrane area and the salt permeability coefficient:

$$M_{TDS,p} = 0.5AK_s(c_{tds,f} + c_{tds,r})$$

The pressure on the permeate side is assumed to be atmospheric:

$$P_p = P_{atm}$$

Capital Costs

The capital costs for reverse osmosis has several components:

1. Pump capital cost
2. Membrane capital cost
3. Pressure vessel and & rack capital cost
4. Energy recovery device (optional)

The total capital costs for RO are calculated as follows, which each component described below:

$$C_{RO} = C_{pump} + C_{mem} + C_{erd} + 3.3C_{pv,r}$$

The value is then multiplied by the Indirect Cost Factor (IDF = 1.65) to arrive at the final fixed capital for reverse osmosis.

Pump Capital Costs

The pump power is calculated as:

$$p_{pump} = \frac{Q_{in}P_f}{\eta_p}$$

The pump cost is then (Bartholomew et al., 2018):

$$C_{pump} = p_{pump}\frac{53}{10^5 \times 3600}^{0.97}$$

Membrane Capital Costs

The cost per meter squared of membrane area is $30 assumed (Bartholomew et al., 2018). The membrane costs are calculated as:

$$C_{mem} = A \times 30$$

Pressure Vessel & Rack Capital Costs

The pressure vessel cost is a function of area and the number of vessels per membrane area (assumed to be 0.025 vessels/m2) and the vessel cost (assumed to be $1000) based on the default EPA assumptions:

$$C_{pv} = A * 0.025$$

The rack capital costs assumes 2 trains, 150 ft start, and 5 ft per additional vessel:

$$C_{rack} = (150 + (x_{add}A0.025))33n_{trains}$$

And the total for this component is:

$$C_{pv,r} = C_{pv} + C_{rack}$$

Energy Recovery Device

The capital costs for the ERD option is taken from Bartholomew & Mauter (2019) and is based on the volumetric mass flow into the ERD device [kg/hr]:

$$M_{tot,r} = M_{H20,r} + M_{tds,r}$$

And the capital costs are calculated:

$$C_{erd} = 3134.8M_{tot,r}^{0.58}$$

Electricity Intensity

The electricity intensity is a function of the pump power, ERD power, and the flow into the unit.

The pump power is calculated as [kW]:

$$p_{pump} = \frac{Q_{in} P_f}{\eta_p}$$

The ERD power is function of the retentate flow (flow out of the unit), retentate pressure, and the ERD efficiency [kW]:

$$p_{erd} = \frac{Q_{out}(P_r - 1)}{\eta_{erd}}$$

And the electricity intensity for the unit is calculated as [kWh/m3]:

$$E_{RO} = \frac{p_{pump} - p_{erd}}{Q_{in}}$$

Membrane Replacement Rate & Chemical Cost

The membrane replacement rate is included in the other variable operating costs for reverse osmosis.

Membrane replacement costs (assumed to be 25% of area per year):

$$C_{replace} = 0.25 C_{mem}$$

Chemical costs are assumed to equal 1% of the capital cost (Bartholomew et al., 2018).

References

Bartholomew, T. V. and Mauter, M. S. (2019).
“Computational framework for modeling membrane processes without process and solution property simplifications.”
Journal of Membrane Science 573: 682-693.

Bartholomew, T. V., Siefert, N. S., Mauter, M.S. (2018).
“Cost Optimization of Osmotically Assisted Reverse Osmosis.”
Environmental Science & Technology 52: 11813-11821.

Lu, Y.-Y., et al. (2007).
“Optimum design of reverse osmosis system under different feed concentration and product specification.”
Journal of Membrane Science 287(2): 219-229.

US Environmental Protection Agency (2019)
“Work Breakdown Structure-Based Cost Model for Reverse Osmosis/Nanofiltration Drinking Water Treatment”
https://www.epa.gov/sites/production/files/2019-07/documents/wbs-ronf-documentation-june-2019.pdf

Reverse Osmosis Module

class watertap3.wt_units.reverse_osmosis.**UnitProcess** (*args, **kwds)

elect (t)

Parameters: **t** (*int*) – Indexing variable for Pyomo Var()

Returns:

fixed_cap (t, b_cost)

Parameters:

- **t** (*int*) – Indexing variable for Pyomo Var()
- **b_cost** (*object*) – Costing block for unit.

Returns: Fixed capital costs for reverse osmosis [$MM]

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Sedimentation

Unit Parameters

There is one parameter:

- `"settling_velocity"` - *v* the assumed settling velocity for the unit [m/s]:
    - Required parameter

Capital Costs

The capital costs are a function of basin surface area:

$$C_{sed} = 13572 A_{basin}^{0.3182}$$

Basin surface area is calculated as [ft3]:

$$A_{basin} = \frac{Q_{in}}{v}$$

Electricity Intensity

There are no electricity costs associated with sedimentation in WaterTAP3.

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Sedimentation Module

class `watertap3.wt_units.sedimentation.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Sodium Bisulfite Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]

    - Required parameter

Capital Costs

Costing parameters for sodium bisulfite addition are taken from sulfuric acid. The sodium bisulfite solution flow S [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single sodium bisulfite addition unit, a = 900.97 and b = 0.6179. The full cost equation in WaterTAP3 is:

$$C_{bisulf} = 900.97S^{0.6179}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{bisulf} = Q_{in}D_{bisulf}$

- The volumetric flow S [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

    $S = \frac{M_{bisulf}}{\rho_{bisulf}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{bisulf} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1480
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities

DOI:10.1002/9780470260036

Sodium Bisulfite Module

class watertap3.wt_units.sodium_bisulfite_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘dose’: 10}
Fixed capital for sodium bisulfite addition is a function of sodium bisulfite dose, sodium bisulfite solution flow, and the number of units.

Parameters: **dose** (*float*) – Sodium bisulfite dose [mg/L]
Returns: Sodium bisulfite addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]
Returns: Sodium bisulfite solution flow [gal/day]

Solution Distribution and Recovery Plant

The solution distribution and recovery plant distributes the irrigated solution to the stacked heap of metal-bearing ores and the recovers that solution for further extraction.

Unit Parameters

There are two parameters:

- `"mining_capacity"` - mining capacity for the mine [tonnes/day]
    - Optional parameter
    - Default value is 922 tonnes/day
    - Must be provided with `"ore_heap_soln"` or default values for both will be used.
- `"ore_heap_soln"` - volume of leach solution needed per mass ore [gal/tonne]
    - Optional parameter
    - Default value is 500 gal/tonne
    - Must be provided with `"mining_capacity"` or default values for both will be used.

Capital Costs

Capital costs for the solution distribution and recovery plant and other associated mine units (i.e. Agglomeration and Stacking, Heap Leaching) are derived from Table 3 in Kappes (2002). The costing components explicitly calculated for these units via regressed data from this table are (associated WaterTAP3 unit in parentheses):

- Mining equipment (Heap Leaching)
- Mine development (Heap Leaching)
- Crushing plant (Heap Leaching)
- Leaching pads/ponds (Heap Leaching)
- Agglomeration/stacking system (Agglomeration and Stacking)
- Solution distribution and recovery plant (Solution Distribution and Recovery Plant)

The costs from this table that are estimated as a fraction of the component costs are:

- Infrastructure (power, water, access roads, site office, service facilities)
- Owner”s preproduction cost
- Engineering, procurement, construction management
- Import duties
- Equipment and materials transport
- Initial operating supplies

Note that laboratory costs and working capital costs from this table are accounted for elsewhere in WaterTAP3 and so are excluded from the unit process calculations.

Capital costs for the solution distribution and recovery plant are a function of the process pumps, plant, and solution distribution piping. These are lumped together in one costing equation that is a function of the mining capacity X [tonnes/day]. This equation is below and is derived from Table 3 in Kappes (2002):

$$C_{s\&d} = 0.00347X^{0.71917}$$

To account for the other tabulated costing components in Table 3, WaterTAP3 calculates the fraction *f* that the other costs are of the component costs (i.e. other costs / component costs). The other costs fraction *f* are determined from a regression of the total cost in Table 3 minus the solution and distribution costs (calculated above) vs. the mining capacities in that table (3,000 and 15,000 tonnes/day):

$$f = 0.3012X^{0.1119}$$

This fraction is multiplied by the cost of the process pumps, plant, and solution distribution piping (calculated above). This is the costing basis for the solution distribution and recovery plant:

$$C_{basis} = C_{s\&d}(1 + f)$$

To create a cost curve based on unit flow, WaterTAP3 scales the unit flow to the recycle water flow for the solution distribution and recovery plant. The recycle water flow is the difference between the heap flow and the make up flow:

$$Q_{recycle} = Q_{heap} - Q_{makeup}$$

The make up flow and heap flow are derived from the user input for `"ore_heap_soln"` q (default is 500 gal/tonne if no user input provided) and `"mining_capacity"` X (default is 922 tonnes/day if no user input provided). So making the proper unit conversions, make up flow is [m3/hr]:

$$Q_{makeup} = 0.17qX$$
$$Q_{heap} = qX$$

And then the final capital costing curve for the solution distribution and recovery plant is:

$$C_{soln\&dist} = \frac{Q_{in}}{Q_{recycle}} C_{basis}^{0.71917}$$

Operating Costs

The operating costs [$/year] for the solution distribution and recovery plant are derived with cost curves regressed from data in Table 5 of Kappes (2002). Included for the system distribution and recovery plant in WaterTAP3 are operational costs relating to:

- Recovery plant operations
- Site maintenance
- Cement for agglomeration
- Cyanide, lime, and other reagents
- Environmental reclamation and closure

The cost curve for all these operational costs is:

$$C_{s\&d} = 7.71759X^{0.91475} = C_{op}$$

Electricity Intensity

Electricity intensity is a function of the mining capacity *M* and the recycle flow and is taken from Kappes (2002) and is calculated with [kWh/m3]:

$$E = \frac{1.8M}{Q_{recycle}}$$

References

Kappes, D.W. “Precious Metal Heap Leach Design and Practice” (2002)
in: *Mineral processing plant design, practice, and control*
pg. 1606-1630, ISBN: 0873352238
http://ore-max.com/pdfs/resources/precious_metal_heap_leach_design_and_practice.pdf

Solution Distribution and Recovery Plant Module

class `watertap3.wt_units.solution_distribution_and_recovery_plant.`**`UnitProcess`** (*args, **kwds)

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Holding/Storage Tanks

Unit Parameters

- `"avg_storage_time"` - storage time for volume calculation [hr]
    - Required parameter
- `"surge_cap"` - desired surge capacity for volume calculation
    - Required parameter
    - Can be zero if no surge capacity is desired

Capital Costs

Storage tank capital costs are calculated as a function of the volume of storage [m3] required V, flow in [m3/hr], storage duration t [hr], and surge capacity needed x:

$$V = Q_{in} t(1 + x)$$

The storage volume is used to calculate capital costs ($MM):

$$C_{tank} = 1.48 \times 10^{-4} V^{1.014}$$

The data to make the regression is from Loh et al. (2002).

Electricity Intensity

There are no electricity costs associated with storage tanks in WaterTAP3.

Reference

Loh, H. P., Lyons, J., White, C.W. (2002)
DOE/NETL-2002/1169 - Process Equipment Cost Estimation Final Report.
United States: N. p., 2002. Web. doi:10.2172/797810.
https://www.osti.gov/servlets/purl/797810

Storage Tank Module

class `watertap3.wt_units.holding_tank.`**`UnitProcess`** (*args, **kwds)

`elect` **()**
WaterTAP3 has no electricity intensity associated with storage tanks.

`fixed_cap` **(**unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘avg_storage_time’: 24, ‘surge_cap’: 0.2}

Parameters:
- **avg_storage_time** – storage time in hours
- **surge_cap** – is the surge capacity used for calculating storage volume, expressed as a fraction of the total flow (e.g. for 20% surge capacity, use 0.2)

Returns: Fixed capital for storage tanks.

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Static Mixer

Unit Parameters

None.

Capital Costs

Capital costs for stati mixer are based off the costing equation in Table 7.2 of Towler & Sinnott (2012). The equation from the reference is for flow in liters per second, and the equation in WaterTAP3 has been adapted to be used for m3/hr:

$$C_{sm} = 14317.14 + 389.5Q^{-57.342}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the static mixer.

Electricity Intensity

None.

Assumptions

- Number of units = 2

References

Gavin Towler & Ray Sinnott (ed.) (2012)
Chemical Engineering Design (Second Edition): Principles, Practice and Economics of Plant and Process Design
Chapter 7 - Capital cost estimating
ISBN: 9780080966601

Static Mixer Module

class `watertap3.wt_units.static_mixer.`**`UnitProcess`** (*args, **kwds)

Sulfuric Acid Addition

Costs for chemical additions are based on the chemical dose required to treat the water and the inlet flow to the unit.

Unit Parameters

There is one unit parameter:

- "dose" - dose of chemical [mg/L]

    - Required parameter

Capital Costs

The sulfuric acid solution flow *S* [gal/day] is used in a cost curve of the general form:

$$C = aS^b$$

For a single sulfuric acid addition unit, *a* = 900.97 and *b* = 0.6179. The full cost equation in WaterTAP3 is:

$$C_{sulf} = 900.97S^{0.6179}$$

This cost is then multiplied by the number of units and the EIF factor for the final FCI for the chemical addition. These parameters were determined by fitting data from Figure 5.5.11 in McGivney & Kawamura (2008).

Electricity Intensity

Electricity intensity for chemical additions is based off the pump used to inject the chemical solution, the chemical solution flow rate, and the influent flow rate. The calculation includes:

- Lift height [ft]:

    h

- The mass flow rate [kg/day] of the solution necessary to achieve the desired dose:

    $M_{sulf} = Q_{in}D_{sulf}$

- The volumetric flow *S* [gal/min] of the chemical solution, which incorporates the solution density [kg/m3]:

    $S = \frac{M_{sulf}}{\rho_{sulf}}$

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

Then the electricity intensity is calculated as [kWh/m3]:

$$E_{sulf} = \frac{0.746Sh}{3960\eta_{pump}\eta_{motor}Q_{in}}$$

Assumptions

- Number of units = 2
- Solution density [kg/m3] = 1781
- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

Reference

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Sulfuric Acid Addition Module

class watertap3.wt_units.sulfuric_acid_addition.**UnitProcess** (*args, **kwds)

elect ()
Electricity intensity.

Returns: Electricity intensity [kWh/m3]

fixed_cap (unit_params**)**
“unit_params” are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {‘dose’: 10}

Returns: Sulfuric acid addition fixed capital cost [$MM]

get_costing (unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow ()
Chemical solution flow in gal/day

Parameters: **solution_density** (*float*) – Solution density [kg/m3]

Returns: Sulfuric acid solution flow [gal/day]

Surface Discharge

Unit Basics

This unit is a terminal unit in WaterTAP3 and represents the cost of discharging waste streams to surface water. This is also the assumed destination for the waste from any unit process if no waste steram is specified in the input sheet.

Unit Parameters

There are two parameters:

- `"pipe_distance"` - distance for piping to discharge to surface water body [mi]:
    - Optional parameter
    - If included in parameters, adds pipe construction cost to capital cost.
- `"pump"` - whether or not to include pumping electricity costs:
    - Optional parameter
    - Options are “yes” and “no”
    - If “yes”, includes electricity calculation.

Capital Costs

The capital costs are a function of flow [m3/hr] and can include piping costs:

$$C_{surf} = 35\frac{Q_{in}}{10417}^{0.873} + C_{pipe}$$

Piping cost assumes an 8 in diameter pipe, and is a function of the pipe length [mi]:

$$C_{pipe} = 0.28 L_{pipe}$$

If the `"pipe_distance"` unit parameter is not included:

$$C_{pipe} = 0$$

Electricity Intensity

Electricity intensity for surface discharge (if included) is based off the pump used. The calculation includes:

- Lift height [ft]:

    h

- The pump and motor efficiencies:

    $\eta_{pump}, \eta_{motor}$

- And the influent flow in [gal/min] and [m3/hr]:

    Q_{gpm}, Q_{m3hr}

Then the electricity intensity is calculated as:

$$E_{surf} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{m3hr}}$$

Assumptions

- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Piping costs derived from the Kay Bailey Hutchinson case study

Surface Discharge Module

class `watertap3.wt_units.surface_discharge.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Seawater Intake

This is the intake unit process for seawater cases.

Unit Parameters

None.

Capital Costs

The capital costs are a function of flow [MGD] are from Voutchkov (2018):

$$C_{sw} = 2.15 \times 10^{-4} Q_{in}^{0.888803}$$

Electricity Intensity

Electricity intensity for seawater intake is based off the pump used. The calculation includes:

- Lift height [ft]:

  h

- The pump and motor efficiencies:

  $\eta_{pump}, \eta_{motor}$

- And the influent flow in [gal/min] and [m3/hr]:

  Q_{gpm}, Q_{m3hr}

Then the electricity intensity is calculated as:

$$E_{sw} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{m3hr}}$$

Assumptions

- Lift height [ft] = 100
- Pump efficiency = 0.9
- Motor efficiency = 0.9

References

Voutchkov, N. (2018).
Desalination Project Cost Estimating and Management.
https://doi.org/10.1201/9781351242738

Seawater Intake Module

class `watertap3.wt_units.sw_onshore_intake.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Tri-Media Filtration

Unit Parameters

None

Capital Costs

The capital costs are a function of flow [MGD] from figure 3.3. in the Texas Water Development Board (2016):

$$C_{tri} = 0.72557 Q_{in}^{0.5862}$$

Electricity Intensity

Electricity intensity is fixed at 0.00045 kWh/m3 from Bukhary et al. (2019).

References

CAPITAL

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

Bukhary, S., et al. (2019).
"An Analysis of Energy Consumption and the Use of Renewables for a Small Drinking Water Treatment Plant."
Water 12(1).

Tri-Media Filtration Module

class `watertap3.wt_units.tri_media_filtration.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

UV + AOP

The UV+AOP module is used to determine costs for both UV disinfection and UV + AOP units.

Capital costs for UV systems in WaterTAP3 are significantly influenced by UV Dose, UVT, and flow. For most accurate capital cost, include facility data with input parameters.

Unit Parameters

This module has one required parameter and three optional parameters for the input sheet:

- `"aop"` - boolean indicating if unit includes AOP or not:
    - Required parameter
    - If `True`, include chemical costs
- `"uvt_in"` - assumed ultraviolet transmittance (UVT) into unit:
    - Optional parameter
    - Default value is 0.9
    - Must be between 0.5 and 0.99 in increments of 0.01
- `"uv_dose"` - Reduction Equivalent Dose (RED) for unit:
    - Optional parameter
    - Default value is 100 mJ/cm2
    - Must be <1200 in increments of 10
- `"chemical_name"` - name of chemical used for oxidant:
    - Optional parameter
    - No default value
    - Can be any chemical but must match *exactly* chemical entry in `catalysts_chemicals.csv`, e.g. `"Hydrogen_Peroxide"`

Capital Costs

Capital costs for UV + AOP includes cost for the UV system and for the oxidant injection system:

$$C_{UV+AOP} = C_{UV} + C_{ox}$$

UV Capital Costs

Capital costs are a function of flow, UV dose, and UV Transmission (UVT). The WaterTAP3 model uses data Table 3.22 in Texas Water Development Board (2016) to interpolate cost values for:

- UVT between 0.5 and 0.99 in increments of 0.01.
- UV Dose between 10 and 1,200 mJ/cm2 in increments of 10.

For the given UVT and UV Dose, WaterTAP3 retrieves cost data for flows between 1 and 25 MGD from `data/uv_cost_interp.csv`. Using this data, a cost curve is fit to a power curve. Once *a* and *b* are known, capital costs for the UV system are determined:

$$C_{UV} = aQ_{in}^{b}$$

Oxidant Capital Costs

The unit can accept any chemical name and dose, but the cost curve used was developed specifically for Hydrogen Peroxide.

Oxidant costs are calculated with:

$$C_{ox} = 1228(Q_{in}D_{ox})^{0.2277}$$

Where the oxidant dose [kg/m3] is taken from the input parameter `"dose"`.

If `"aop"` is `False` in the unit parameters:

$$C_{ox} = 0$$

Electricity Intensity

Electricity intensity for UV/AOP is fixed at 0.1 kWh/m3 and is taken from USEPA (2010).

References

CAPITAL

User's Manual for Integrated Treatment Train Toolbox - Potable Reuse (IT3PR) Version 2.0
Steinle-Darling, E., Salveson, A., Russel, C., He, Q., Chiu, C., Lesan, D.
Texas Water Development Board
December 2016

ELECTRICITY

US Environmental Protection Agency (2010)
"Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities"
https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1008SBM.TXT

UV + AOP Module

class `watertap3.wt_units.uv_aop.`**`UnitProcess`** (*args, **kwds)

`fixed_cap` **(**unit_params**)**
"unit_params" are the unit parameters passed to the model from the input sheet as a Python dictionary. EXAMPLE: {'aop': True, 'uv_dose': 350, 'dose': 5, 'chemical_name': 'Hydrogen Peroxide'}

Parameters:

- **aop** (*bool*) – (**required**) Boolean that determines if UV is used with AOP. Must be either True or False
- **uvt_in** (*float*) – (**optional**, default is 0.9) UV transmission (UVT) into unit
- **uv_dose** (*float*) – (**optional**, default is 100) Reduction Equivalent Dose (RED) [mJ/cm2]
- **dose** (*float*) – (**optional**, no default) Dose for oxidant (if AOP) [mg/L]
- **chemical_name** (*str*) – (**optional**, default is `'Hydrogen_Peroxide'`) Name of oxidant used for AOP.

Returns: Fixed capital for UV or UV+AOP unit [$MM]

get_costing **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

solution_vol_flow **()**
Determine oxidant solution flow rate in gal / day

Returns: Oxidant solution flow [gal/day]

uv_regress **()**
Determine a, b costing parameters as a function of flow, UVT, and UV dose for unit.

Parameters:

- **flow_in** (*float*) – Volumetric flow into unit [MGD]
- **uvt_in** (*float*) – UV transmission (UVT) into unit
- **uv_dose** (*float*) – UV dose used by the unit [mg/L]

Returns: a, b

Water Pumping Station

Unit Basics

This is a pump unit in WaterTAP3.

Unit Parameters

There are three unit parameters:

- `"pump_type"` - the type of water pumping station:
    - Required parameter
    - Options are “raw” or “treated”
    - Different costing values are used for each option
- `"pump_power"` - pump power if available [hp]:
    - Optional parameter
- `"lift_height"` - amount of dynamic head [ft]:
    - Optional parameter
    - Default value is 100 ft

Capital Costs

Depending on the value for `"pump_type"`, different cost curves are used for the general form with flow in [MGD] from McGivney & Kawamura (2008):

$$C_{wps} = aQ_{in}^{b}$$

For `"pump_type"` = “raw”:

- a = 19370.36
- b = 0.9149

For `"pump_type"` = “treated”:

- a = 40073.43
- b = 0.8667

Electricity Intensity

If there is no input for `"pump_power"`, electricity intensity is a function of flow [gpm] and the unit parameter `"lift_height"` h:

$$E_{wps} = \frac{0.746 Q_{gpm} h}{3960 \eta_{pump} \eta_{motor} Q_{in}}$$

With assumed pump and motor efficiencies of 90%.

Otherwise, the input for `"pump_power"` is converted from horsepower to kW and electricity intensity is:

$$E_{wps} = \frac{p_{pump}}{Q_{in}}$$

References

William McGivney & Susumu Kawamura (2008)
Cost Estimating Manual for Water Treatment Facilities
DOI:10.1002/9780470260036

Water Pumping Station Module

class `watertap3.wt_units.water_pumping_station.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Well Field

Unit Parameters

There are two unit parameters:

- `"pipe_distance"` - pipe distance to be included in costing model [miles]
    - Optional parameter
    - If not provided, piping cost is not included in cost model
    - Cost is $280,000 per mile assuming an 8 in pipe
- `"pump"` - to include pumping costs
    - Optional parameter
    - Options are “yes” or “no”
    - Default value is “yes”

Capital Costs

The capital costs are a function of flow [m3/hr] from Voutchkov (2018). If a pipe distance is not provided, the capital costs are:

$$C_{wf} = 4731.6 Q_{in}^{0.9196}$$

If pipe distance d is provided, the piping cost is:

$$C_{pipe} = 280000 d$$

And the total cost then would be:

$$C_{tot} = C_{wf} + C_{pipe}$$

Electricity Intensity

There are no electricity costs associated with well field in WaterTAP3.

References

Voutchkov, N. (2018).
Desalination Project Cost Estimating and Management.
https://doi.org/10.1201/9781351242738

Well Field Module

class `watertap3.wt_units.well_field.`**`UnitProcess`** (*args, **kwds)

`get_costing` **(**unit_params=None**,** year=None**)**
Initialize the unit in WaterTAP3.

Index

E

F

G

S

U