DuPont Water Solutions

WAVE Technical Manual

Version 5

January 2020

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1 General WAVE Features

The Water Application Value Engine (WAVE) is a new modeling software program that integrates three of the leading technologies (ultrafiltration, reverse osmosis and ion exchange resin) into one comprehensive platform. The WAVE software is used to design and simulate the operation of water treatment systems using the UF, RO, and IER component technologies.

The following Introductory section includes description of the following general WAVE features:

1.1 Defining the User Information

When starting a project in WAVE it is advisable to put in user information including name, company, customer etc. This can be done as follows:

1. Click on "User Settings" in the top ribbon

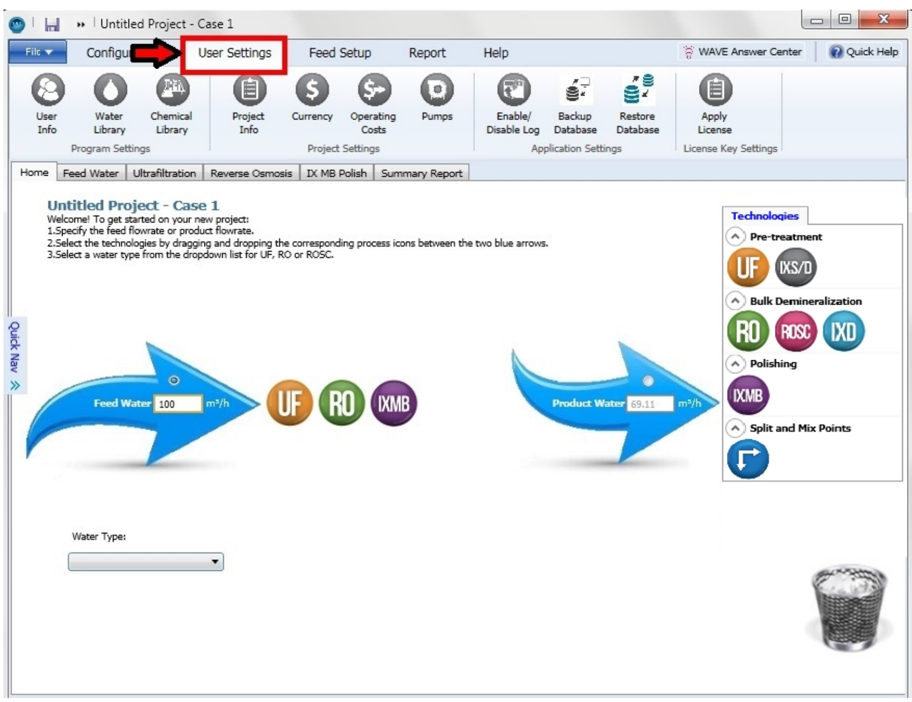


Figure 1. Selection of User Settings to specify User Information

Form No. 45-D01378-en, Rev. 5
January 2020

2. Click on “User Info."

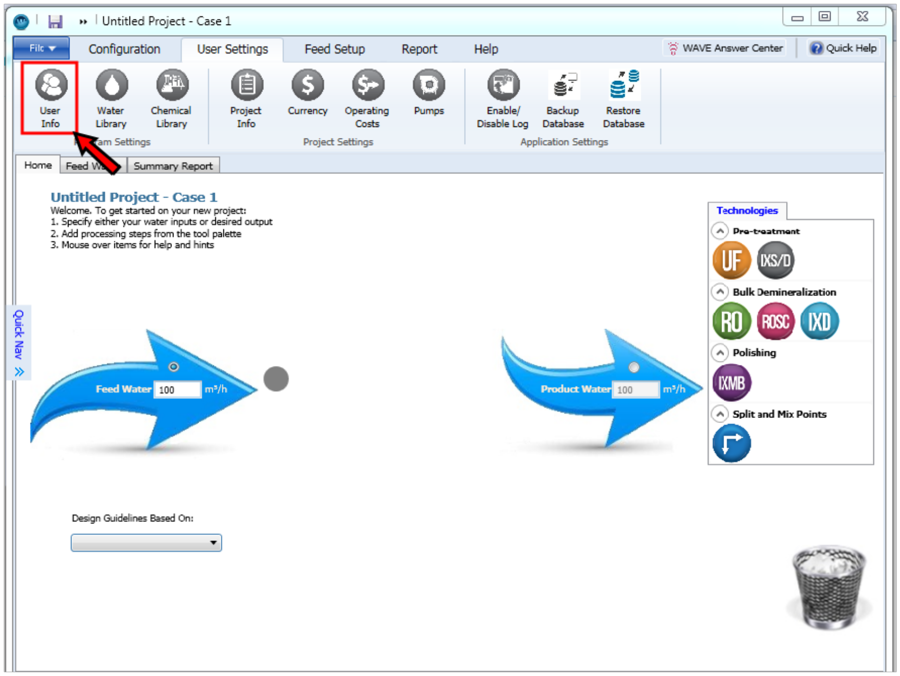


Figure 2. Selection of User Info button to specify User Information

3. Specify the User Information and click on ‘Save’

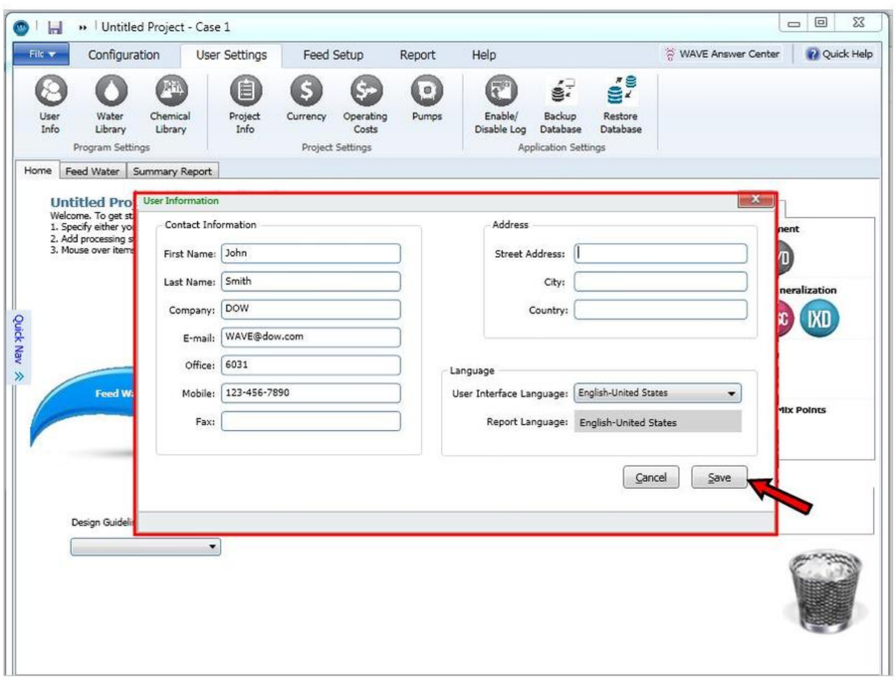


Figure 3. Specification of user information

Note: The following fields are used to pre-populate the 'Project Information' window:

- First Name and Last name (these are combined to give the "Prepared by:" field)
- Company
- Country
- User Interface (UI) Language - Currently, the User Interface (UI) Language choices are English, Spanish, Portuguese, and Chinese. The Report Language is the same as the UI language.

1.1.1 Defining the User Language

This can be done by the following steps:

1. Click on "User Settings" in the top ribbon

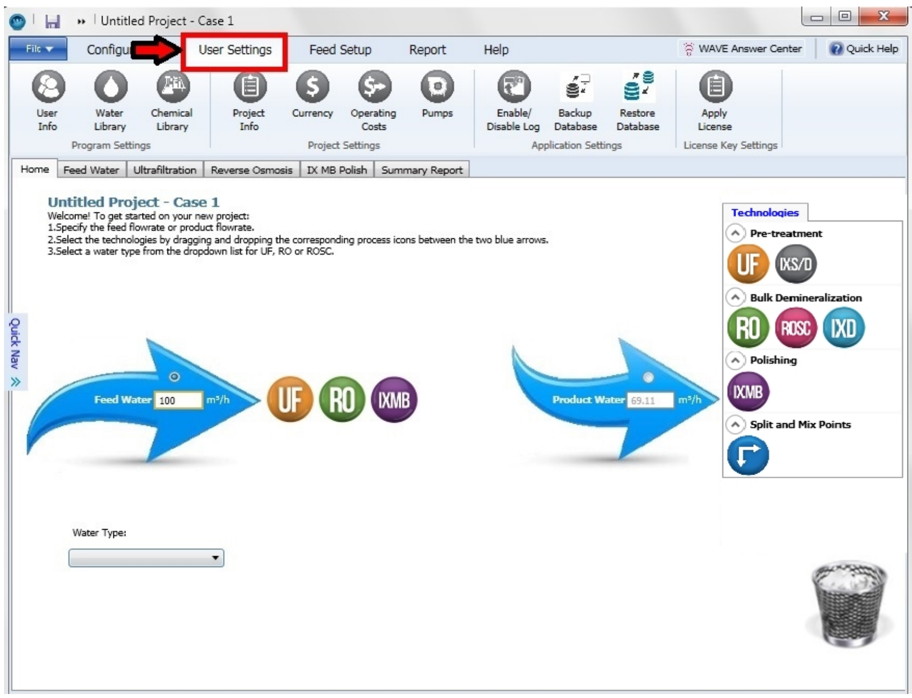


Figure 4. Selection of User Settings to specify User Information

Form No. 45-D01378-en, Rev. 5
January 2020

2. Click on “User Info.

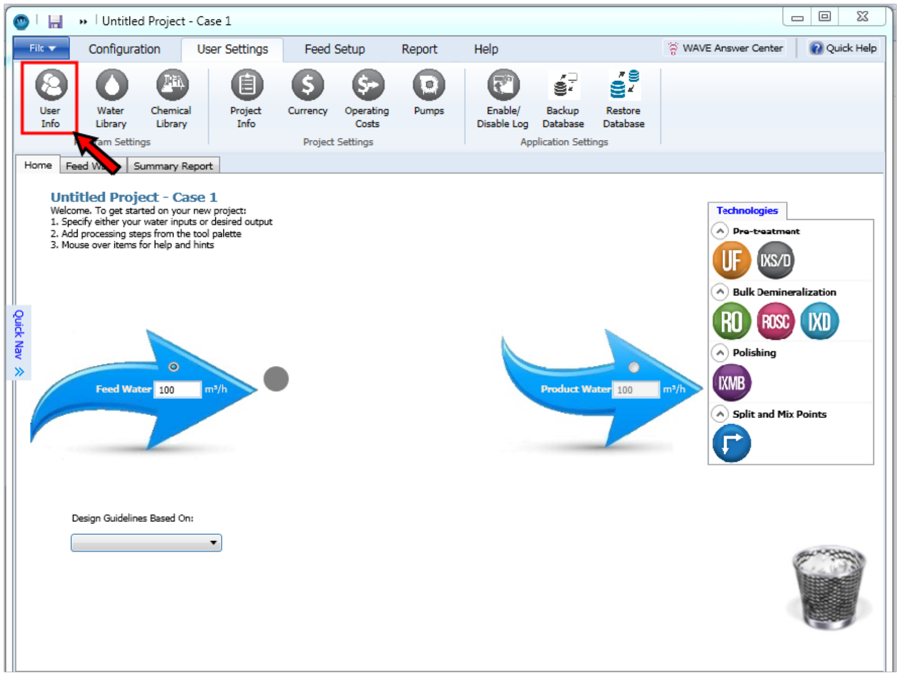


Figure 5. Selection of User Info button to specify User Information

3. Select a language from the lower right hand side and click on ‘Save’

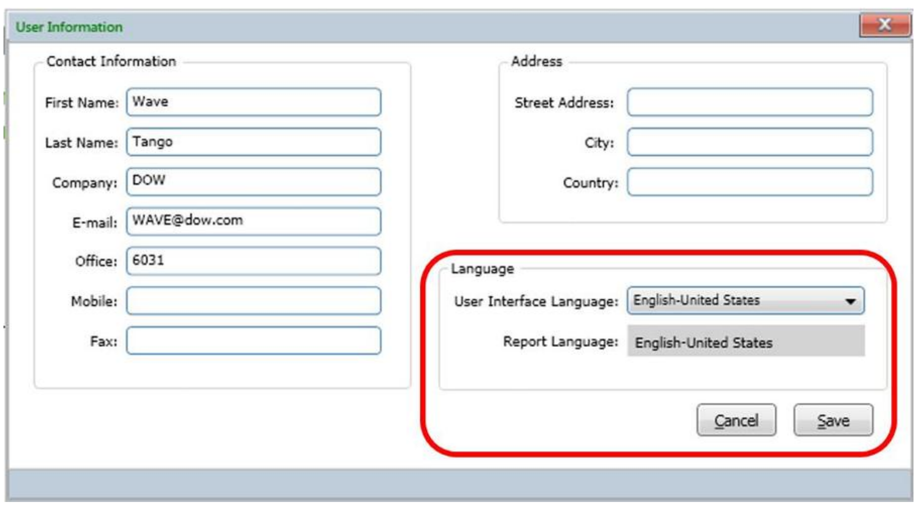


Figure 6. Specifiying a language

Note: Currently, the User Interface (UI) Language choices are English, Spanish, Portuguese, and Chinese. The Report Language is the same as the UI language.

1.2 Defining the Project Information

When starting a project in WAVE it is advisable to put in project information including project name, date, description etc. This can be done as follows:

1. Click on "User Settings" in the top ribbon
2. Click on "Project Info."

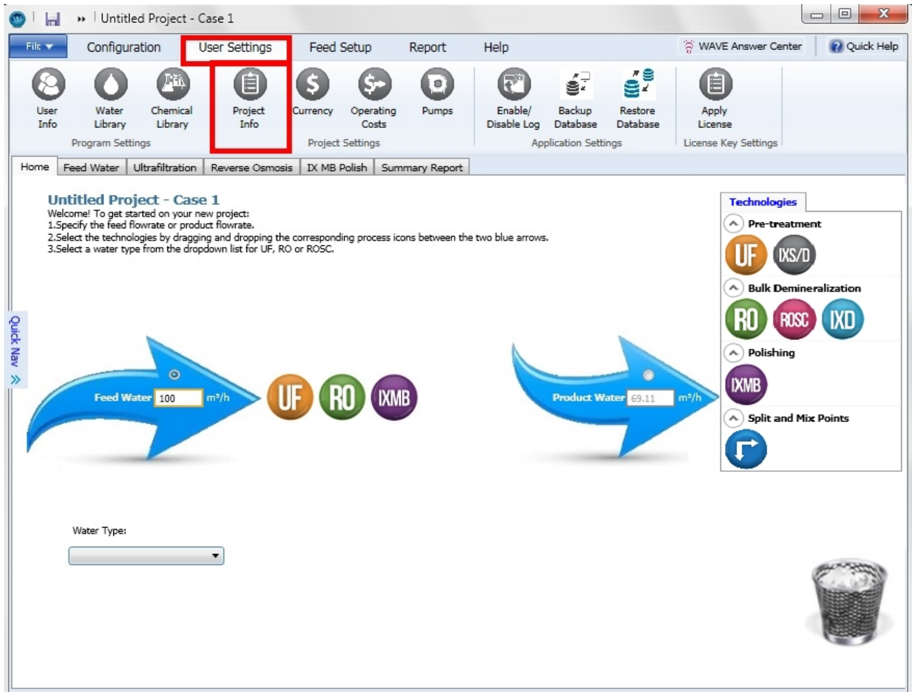


Figure 7. Selection of the Project Info button to specify Project Information

3. Specify the Project Information and click on 'Save'

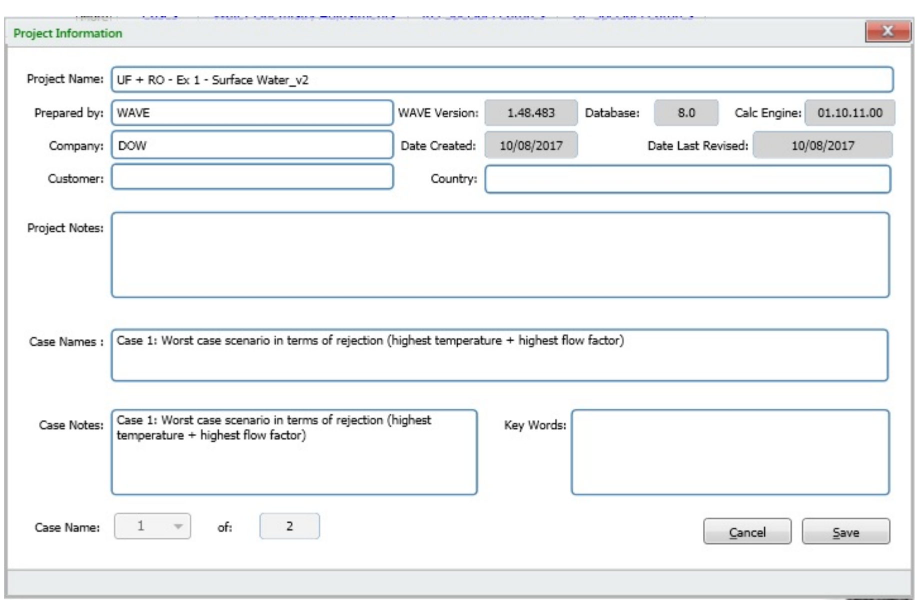


Figure 8. Specification of the Project Information

Notes:

- The following fields are taken from the 'User Information' window: 'Prepared by', 'Company' and 'Country' by default. The user can update them on the 'project Information' window.
- The 'WAVE version', 'Database', 'Calc Engine', 'Date Created' and 'Date Last Revised' are not user inputs.
- The number of cases is determined by the Case Manager. Users cannot update the number of cases at the Project Information window.
- The Case Notes are displayed in the Case Manager and Quick Nav windows as well as the Detailed Report.

1.3 Currencies and Exchange Rates

WAVE allows the user to specify currencies for cost calculation. The steps involved are:

1. Click on "User Settings" in the top ribbon

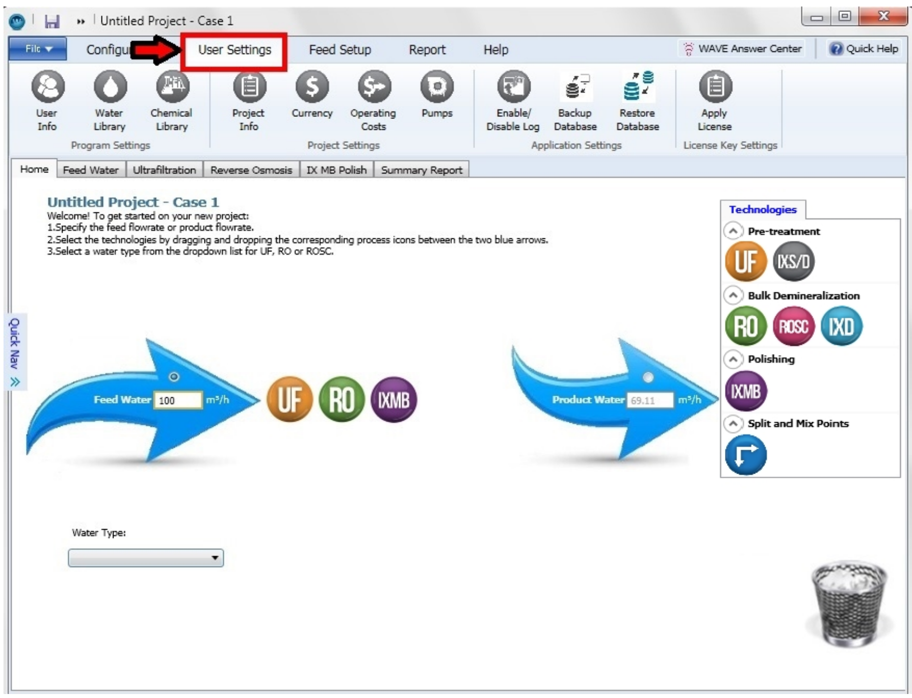


Figure 9. Selection of User Settings to specify Currencies and Exchange

2. Click on "Currency"

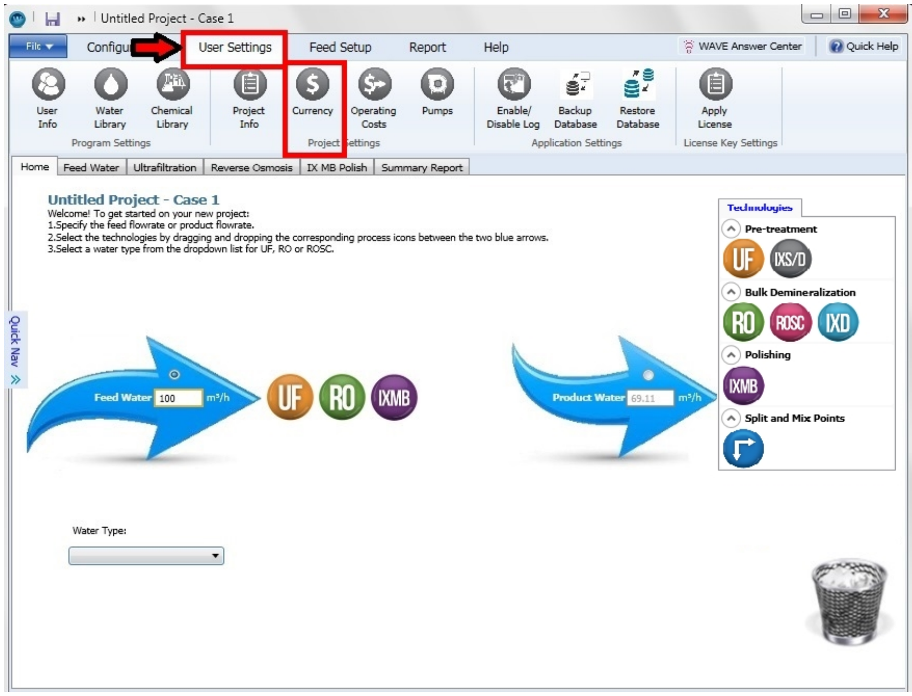


Figure 10. Selection of Currency to specify Currencies and Exchange Rates

3. Select a currency and update the conversion rate to the USD. If necessary, make these values the default values.

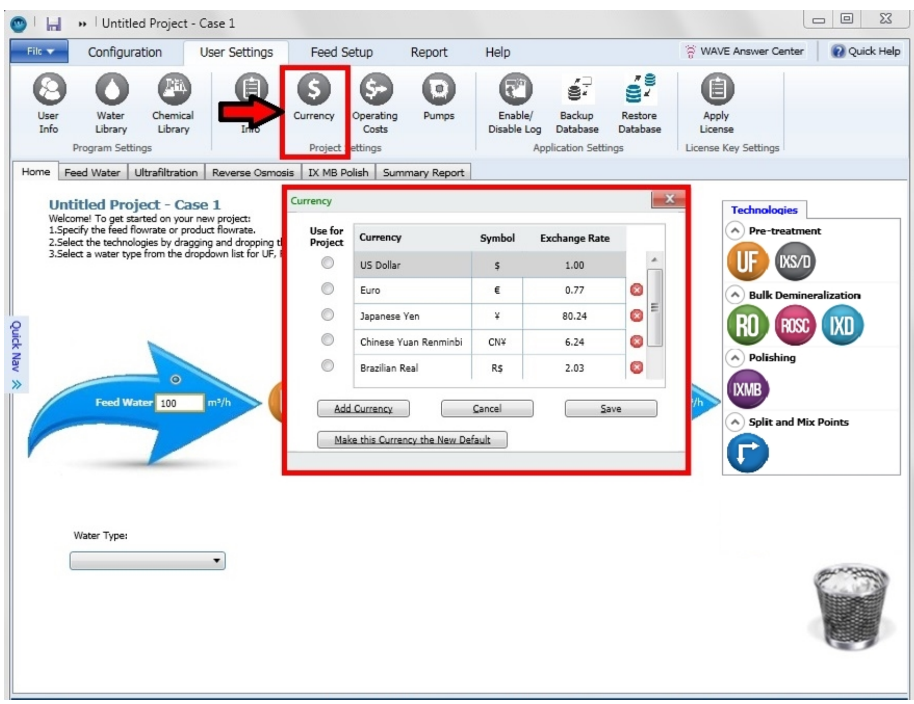


Figure 11. Specification of Currencies and Exchange Rates

4. Click "Save"

Notes:

- The currency selected in the 'Currency' window will be used in subsequent cost calculations and in specifying the Operating Cost.
- Users can add a new currency by clicking on "Add Currency" in the 'Currency' window.

1.4 Chemical Library

Multiple chemicals are used in WAVE to adjust pH, coagulate solids, clean UF modules, prevent scaling, regenerate ion exchange resins etc. In WAVE, these chemicals can be common substances (e.g. NaOH, HCl) at various concentrations or user defined chemicals. These chemicals can be defined as shown below:

1. Click on 'User Settings' in the top ribbon

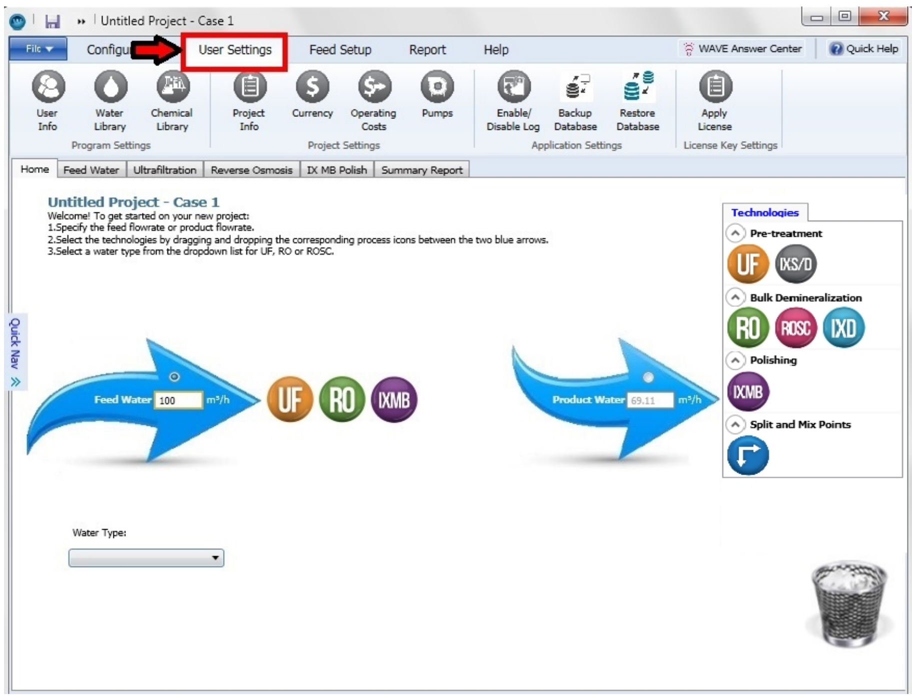


Figure 12. Selection of User Settings to specify Chemicals

2. Click on 'Chemical Library'

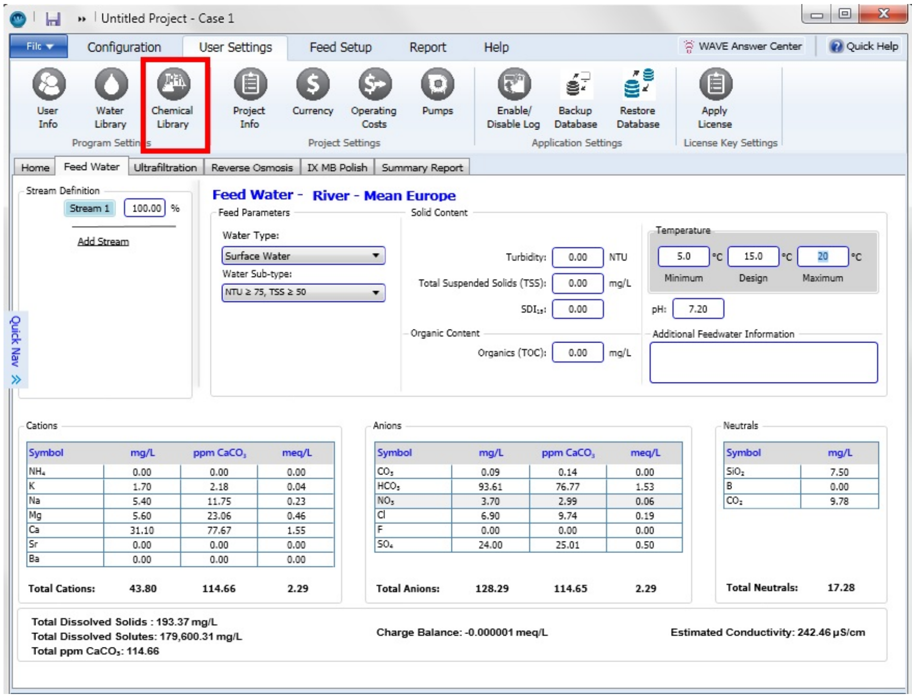


Figure 13. Selection of the Chemical Library to specify Chemicals

3. Select which chemicals would appear in dropdown boxes and which chemicals are to be included in cost calculations

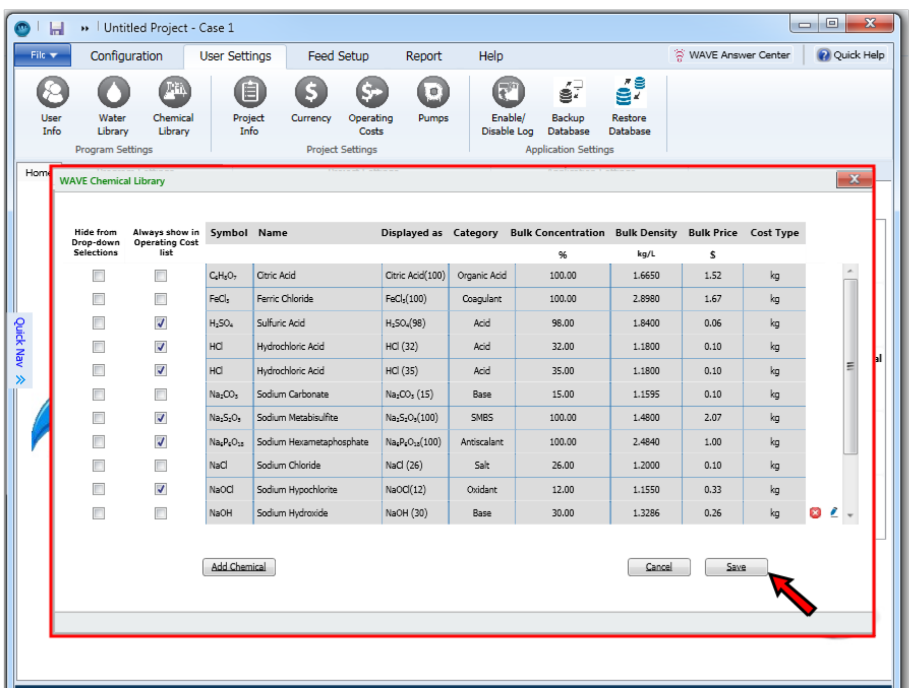


Figure 14. Specification of Chemicals

1.4.1 Adding a New Chemical

1. To add a new chemical, click on "Add Chemical"

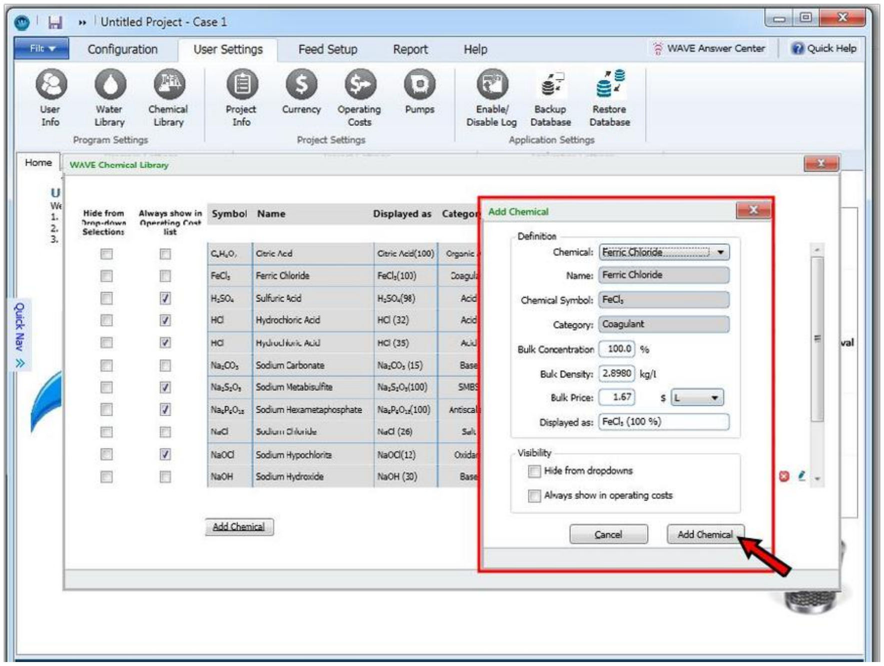


Figure 15. Click on add chemical

2. Click on the "Chemical" dropdown arrow and select from the different categories 'Antiscalant', 'Organic Acid', 'Coagulant' and 'Oxidant' are generic categories while the rest of the categories refer to specific substances.

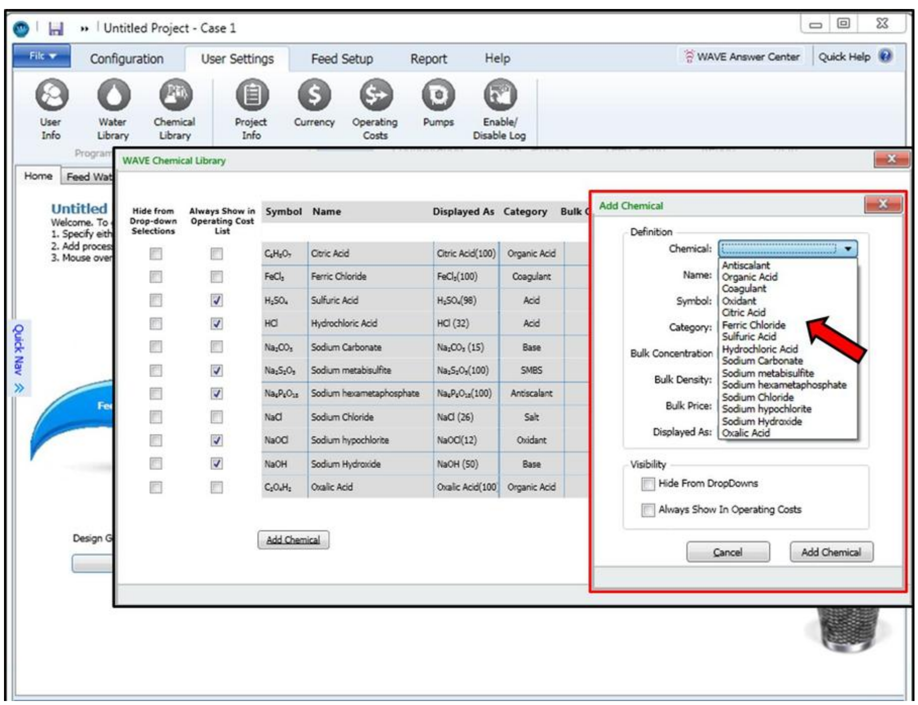


Figure 16. Selection of a chemical category

3. Fill out information on the Chemical as shown in and click “Add Chemical”.

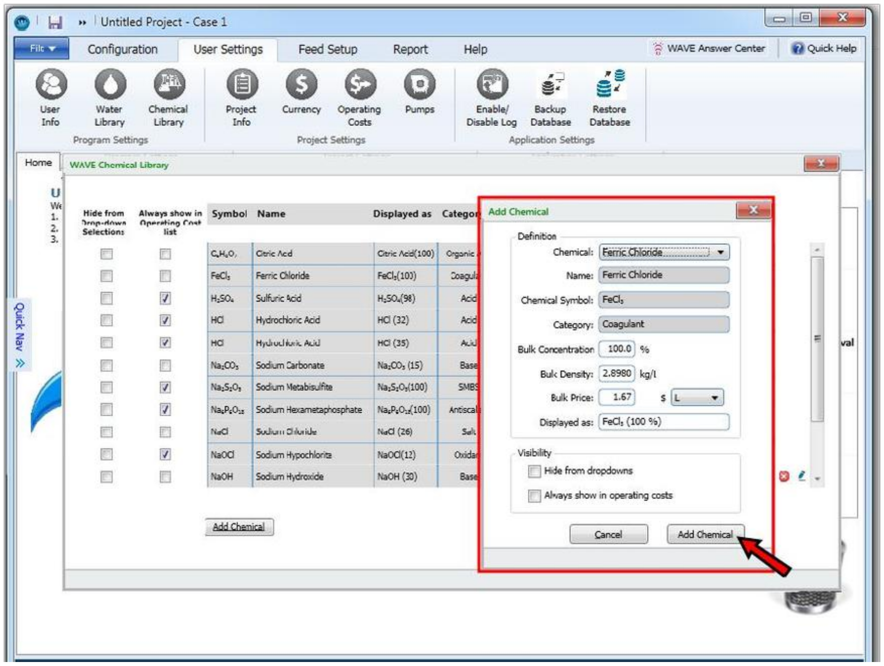


Figure 17. Specification of a new chemical

Notes:

- By default, WAVE uses chemical prices of $/kg. Users can also specify prices in $/lb, $/L and $/gal (when using US currency) in the ‘Operating Costs’ window.
- The user can specify whether the chemical should be shown in dropdown lists and if it is to be included in cost calculations in the “Add Chemical” window
- Added Chemicals can be removed from the Library by clicking on the red circles which appear next to the added chemicals.

1.5 Operating Costs

To calculate operating costs in WAVE, water purchase, wastewater disposal and electricity rates can be specified in the 'Operating Costs' window. The steps involved are:

1. Click on "User Settings" in the top ribbon

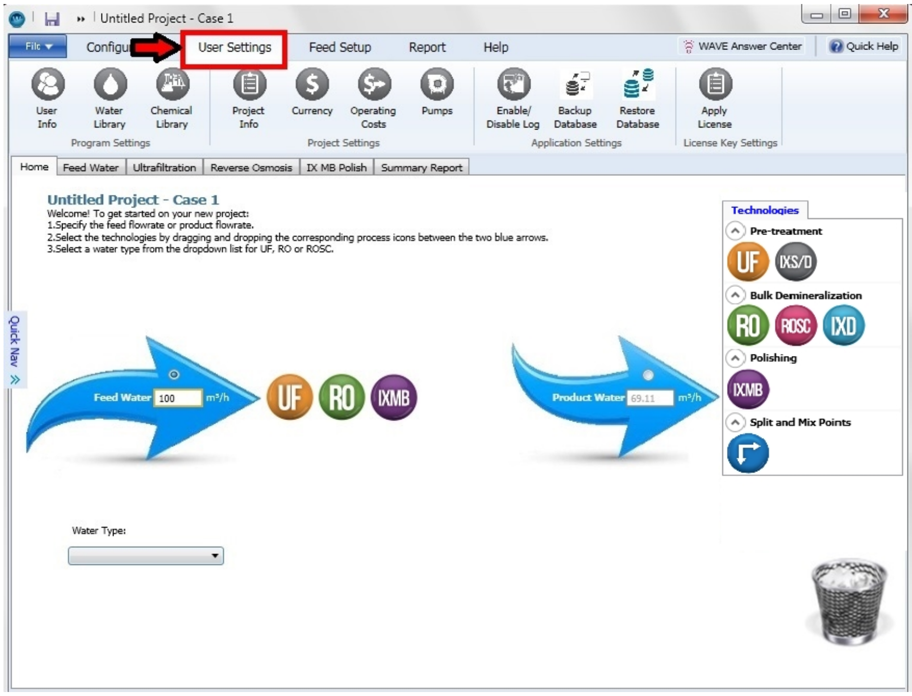


Figure 18. Selection of User Settings to specify Operating Costs

2. Click on "Operating Costs"

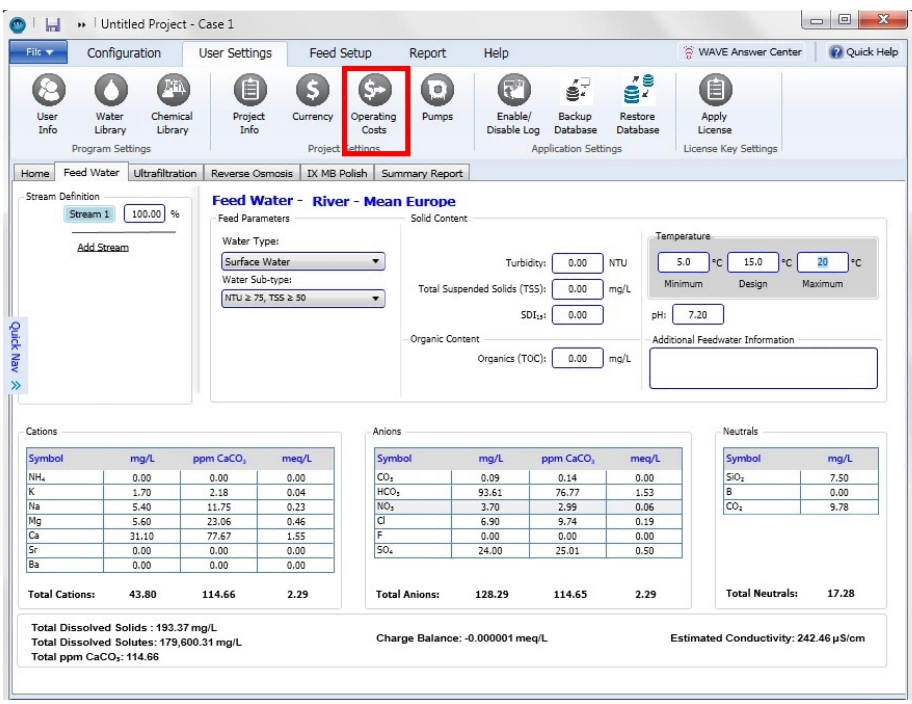


Figure 19. Selection of the Operating Costs window

3. Specify operating cost values and, if necessary, make them default values

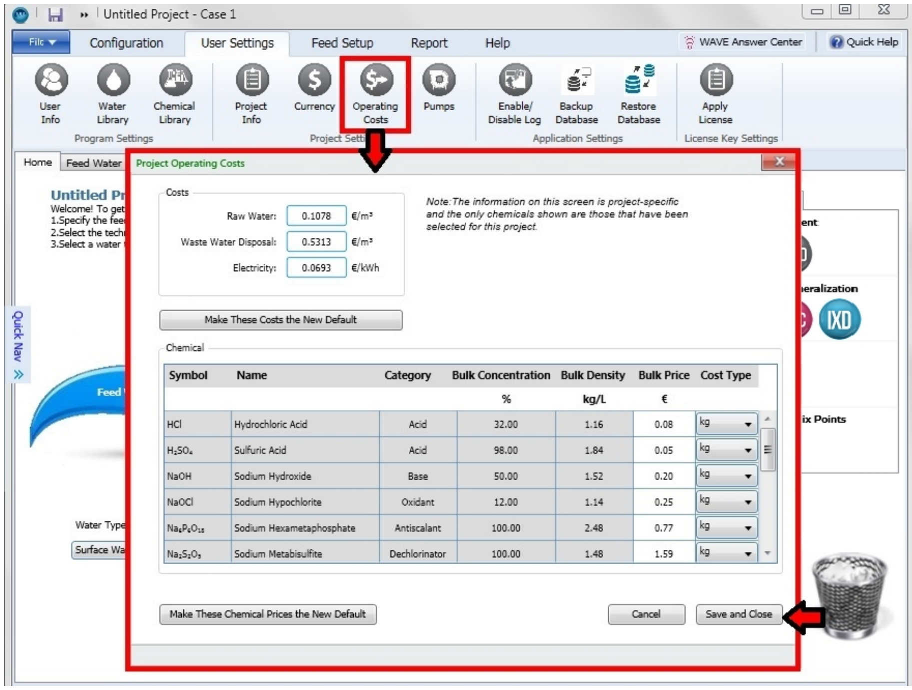


Figure 20. Specification of Operating Costs.

4. Click “Save”.

Note: The information on this screen is project specific and the only chemicals shown are those that have been selected within this project

1.6 Pump Efficiencies

Mechanical and electrical efficiencies of the pumps and compressors used for UF, RO and IX can be specified in WAVE. This is done as follows:

1. Click on "User Settings" in the top ribbon

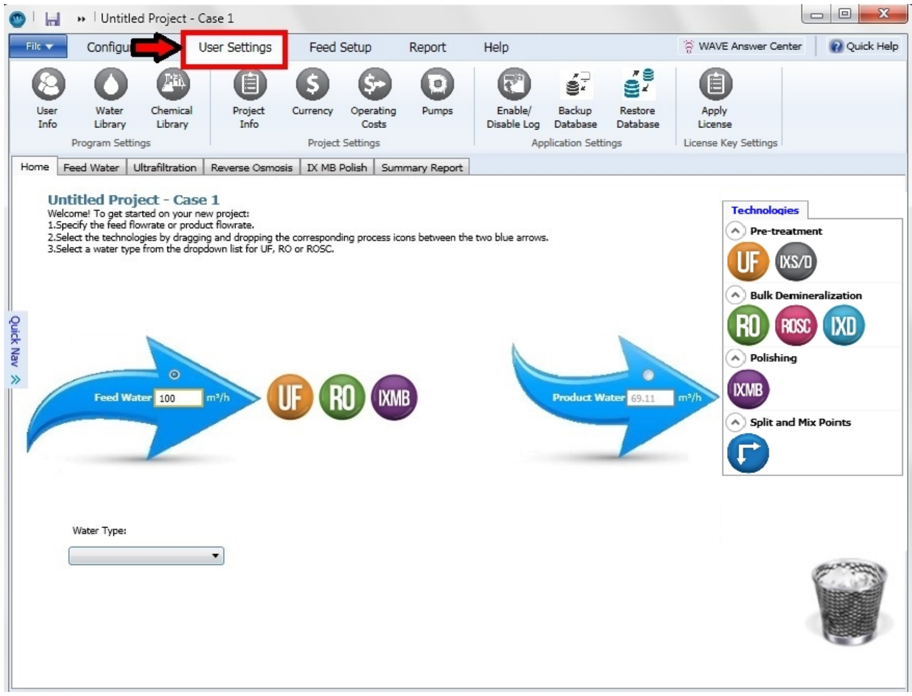


Figure 21. Selection of User Settings to specify Pump Efficiencies

2. Click on "Pumps"

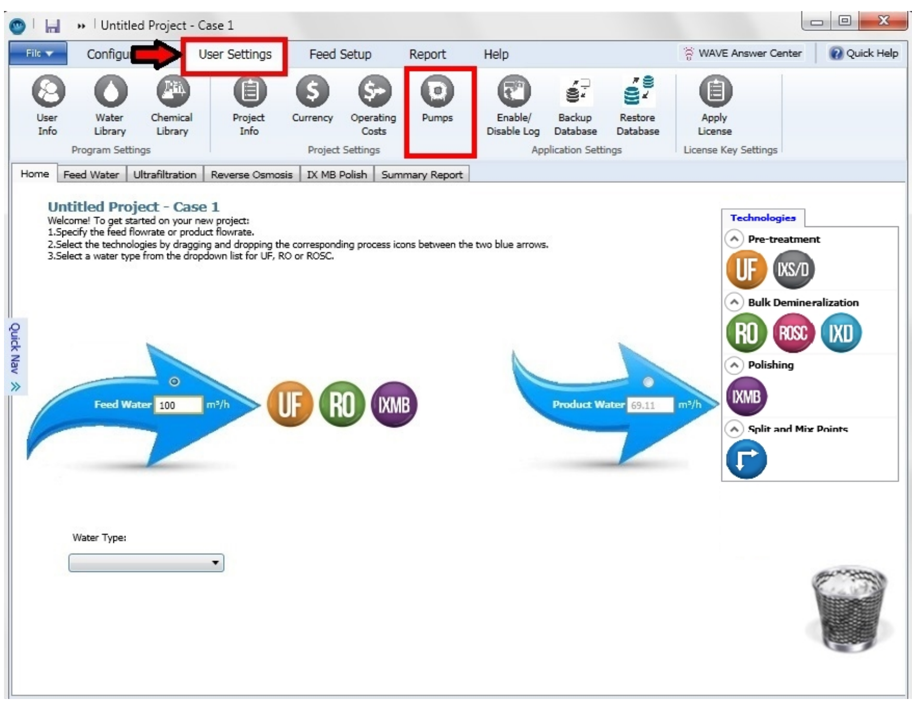


Figure 22. Selection of the Pumps window

3. Specify efficiency values and, if necessary, make them default values

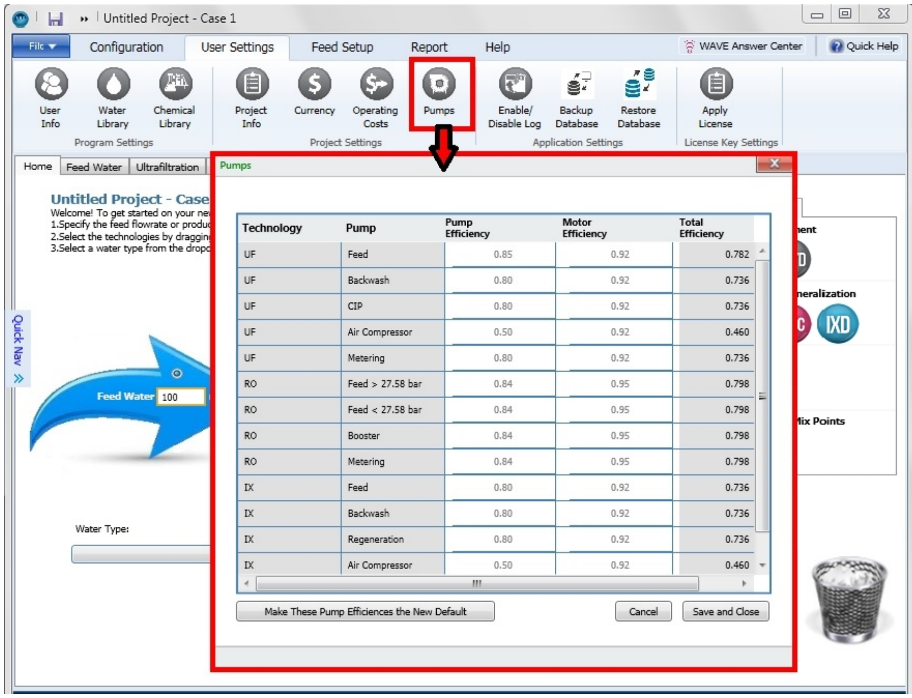


Figure 23. Specification of Pump Efficiencies

4. Click “Save”.

1.7 Units of Measure

The WAVE user can switch between different units of measure. The steps are:

1. Click on “Configuration” in the top ribbon

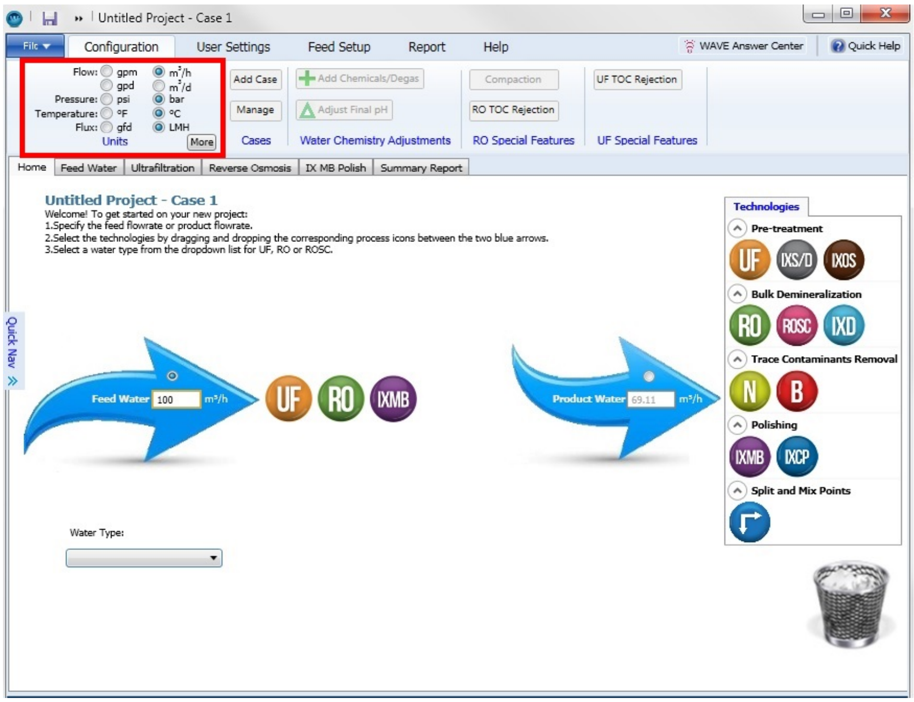


Figure 24. Selection of Configuration to specify Units of Measure

2. Switch units as needed by clicking on the radio buttons

3. Click on the ¨More¨ button at the bottom right corner of the box to expand the list of units

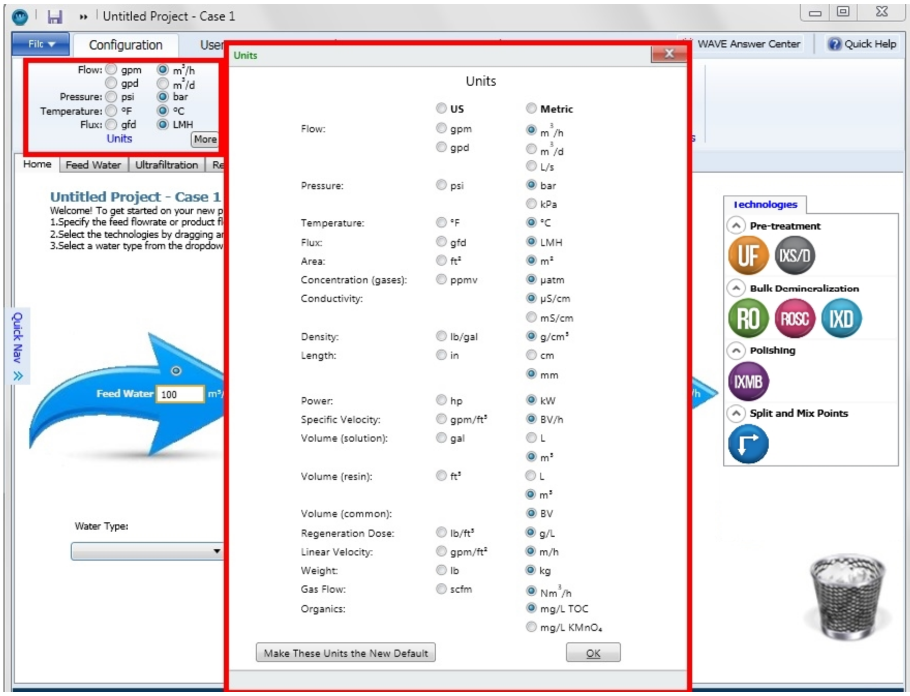


Figure 25. Selection of Configuration to specify Units of Measure

4. Select the appropriate units and click "OK".

Notes:

- Users can make the selection the new default by clicking on ¨Make These Units the New Default¨
- Users can switch between US and SI units by clicking on the radio buttons at the top

1.8 Specifying the System Feed and Product Flows

Feed and product water flowrates can be specified using the text boxes in the middle of the blue arrows

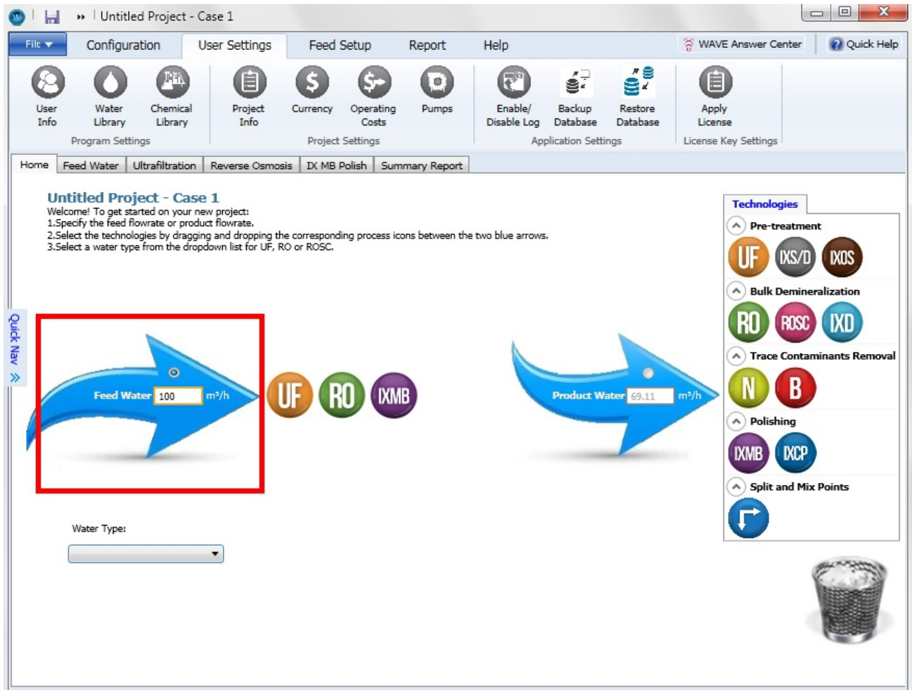


Figure 26. Specification of feed flowrate in a system design

First, Feed or Permeate flow option should be selected using the radio button in the upper part of the arrow, later the flowrate can be specified.

Notes:

- WAVE would display a warning if the Feed or Product flowrates are specified as 0 or a negative number.
- Given a feed water flowrate, WAVE would calculate a product flowrate based on a default recovery. Given a product water flowrate, WAVE would calculate a feed flowrate based on a default recovery.

- Users can define a preliminary recovery for each icon and thus define either the feed flowrate and recovery or product flowrate and recovery (as shown in Figure 27).

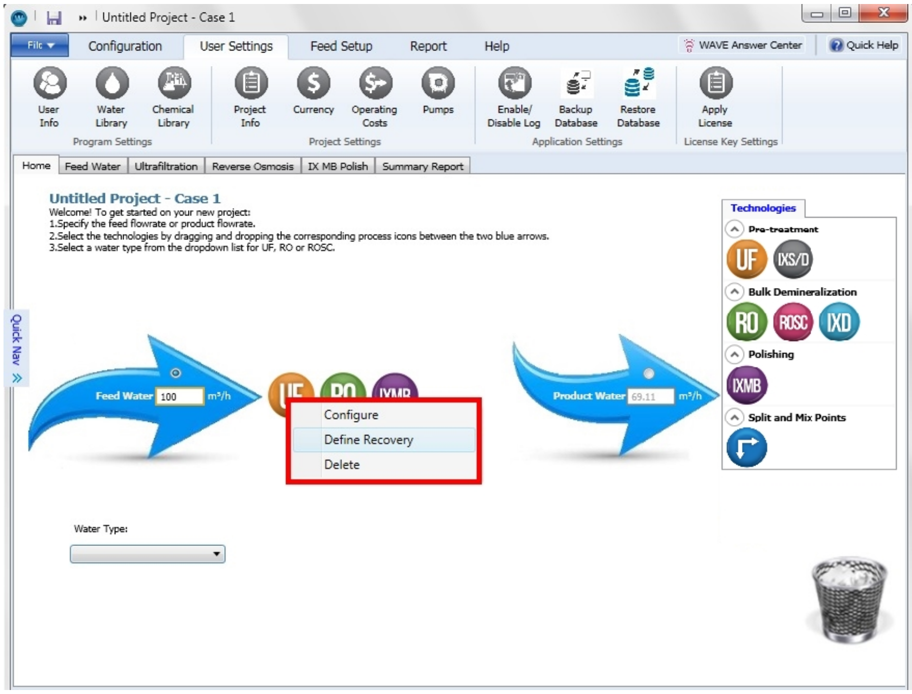


Figure 27. Specification of preliminary recovery

- Detailed system design with a user defined recovery is currently only possible for RO and ROSC. For other technologies recovery is known only after all the calculations are completed.
- WAVE does not allow simultaneous specification of the feed and product flowrates.

1.9 pH Adjustment of the Final Product

This involves adjustment of the pH of the Permeate. This feature, as described in Section1, is available to all three technologies (UF, RO, IX). The steps are as follows (Figure 28):

1. Click on the **Home** Tab if you are in a different Tab or Window.
2. On the Configuration Ribbon, in the Water Chemistry Adjustments section, click on "Adjust Final pH".
3. Click on the "pH" button.

4. Specify the pH of interest then click “OK”.

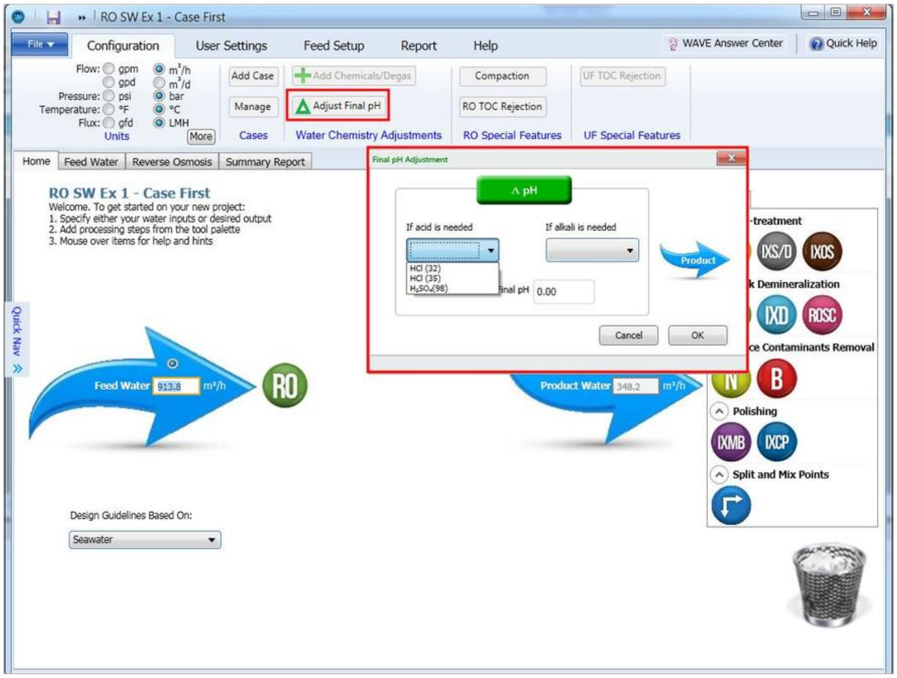


Figure 28. Specification of RO/NF/ROSC System Pass Feed pH Adjustment

Notes:

- In WAVE, pH adjustment can be deactivated by choosing “pH” button a second time. The green dots would turn gray.
- In WAVE, pH specifications are limited to between 0 and 14.
- The list of chemicals used for pH adjustment is defined by the user as described in Section 1.
- WAVE allows the simultaneous selection of “pH” without an intermediate degasification step. Thus the user is urged to review the pH adjustment selections carefully.

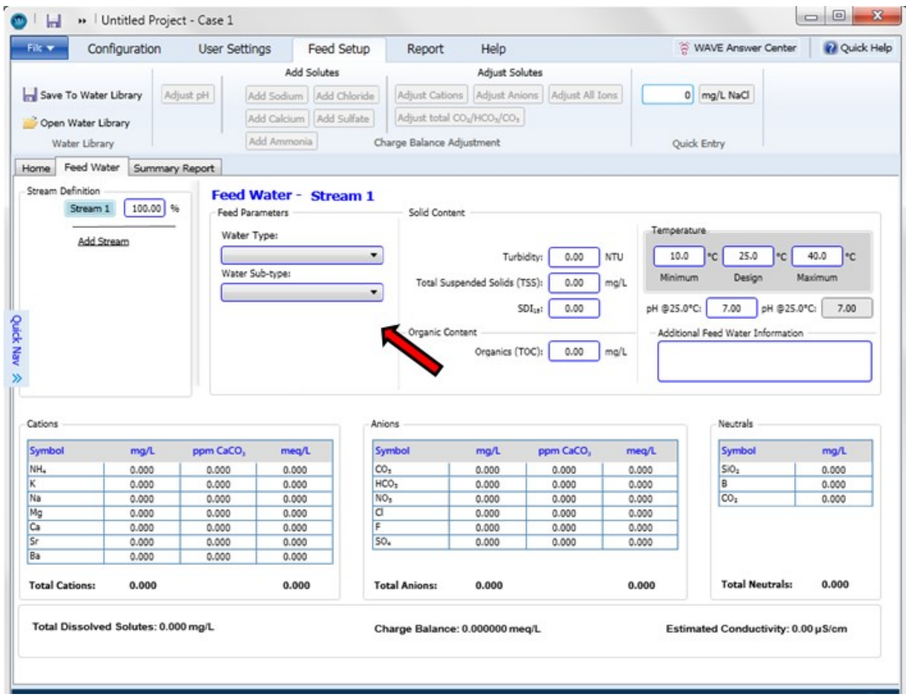
2 Specifying the Feed Water Composition

2.1 Defining the type of water

The Water Types and Subtypes used in WAVE are shown in the WAVE Water Types and Subtypes visible in UF. below. As WAVE is a multi-technology platform, the same Water Types would be used for the UF, RO and IX. The Subtypes may be named differently depending on the technology.

2.2 Specifying Water Types and Subtypes

The Water Types and Subtypes are used in WAVE to determine design guidelines. These water types and subtypes are dependent on technology. In WAVE, there are two locations to specify Water Types.



2.2.1 Specifying the Water Type in the Home Tab

The steps needed to specify the water Type in the Home Tab are given below and shown in Figure 29:

1. Select the "Home" tab
2. Select the appropriate Water Type from the dropdown menu.
3. Select the "Feed Water" Tab

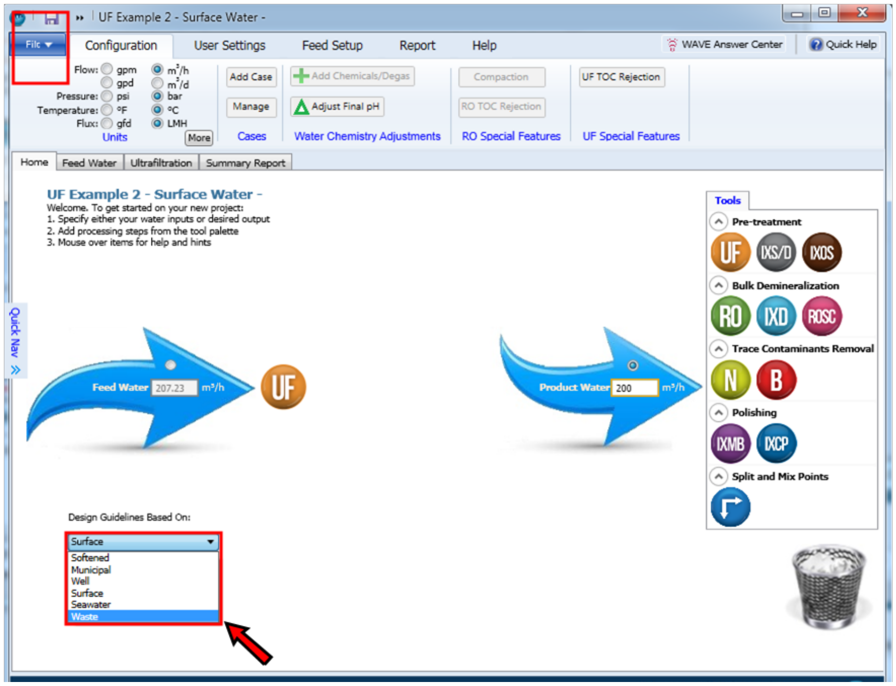


Figure 29. Choosing the Feed Water Type in the Home Tab in WAVE

2.2.2 Specifying the Water Type and Subtype in the Feed Water Tab

The steps needed to specify the water Type in the Feed Water Tab are given below.

1. Select the "Feed Water" tab
2. Select the appropriate Water Type from the dropdown menu.
3. Select the appropriate Water Subtype from the dropdown menu

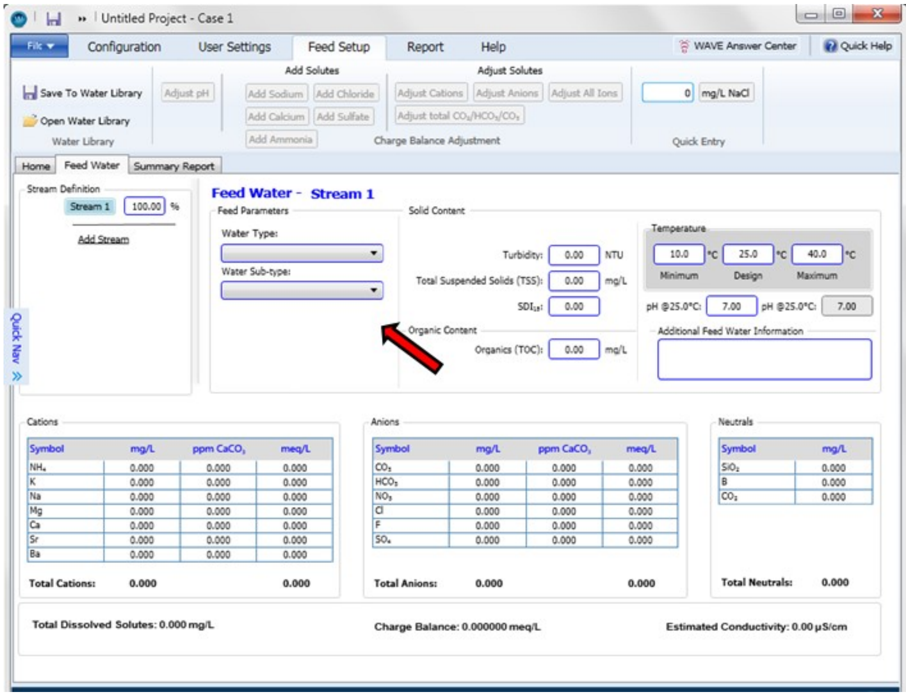


Figure 30. Choosing the Feed Water Type and Subtype in the Feed Water Tab in WAVE

Notes:

- There is only one location to select Water subtypes in WAVE: the Feed Water Tab.
- In WAVE, the water type selected in the Home Tab is reflected in the Feed Water Tab. A Water Subtype (one suggesting the most conservative design) is picked by WAVE by default. The user can change the water subtype in the Feed Water Tab.
- Changing the Water Type in the Feed Water Tab would also automatically change the Water Type in the Home Tab. However, changing the Water Type in the Feed Water Tab would not change the Water Subtype in the same Tab.
- WAVE would allow the user to proceed to the Feed Water tab without selecting a water type for RO and ROSC. It would not allow this for UF
- The choice of a water profile from the Water Profile Library does not necessarily correlate to the choice of an appropriate design guideline. For instance, one can select a Seawater Profile from the Library but, after the Water Profile is copied to the Feed Water Tab, the design guidelines do not change to Seawater guidelines

Specifying the Water Type and Subtype for Ultrafiltration

For UF, the NTU Turbidity and TSS are key differentiators.

Table 1. WAVE Water Types and Subtypes visible in UF.

Source Water	Turbidity (NTU)	TSS (mg/L)
Well Water	< 2	< 5
Softened / Municipal Water	< 2	< 5
Surface Waters	< 2	< 5
	< 5	< 10
	5 - 15	< 20
	15 - 50	< 30
	50 - 75	< 50
Seawater	< 5	< 5
	< 10	< 20
	< 20	< 40
Wastewater (Industrial, Secondary, Tertiary Effluent)	< 3	< 5
	< 5	< 10
	5 – 10	< 20
	10 – 20	< 30
	< 30	< 40

Notes:

- RO permeate is not included as a Water Type because it is considered unlikely that RO permeate would need UF treatment.
- Depending on the values introduced in the water characterization, WAVE already gives the water subtype recommended.

Defining RO/ROSC Design Guidelines, Water Types and Subtypes

DuPont Water Solutions provides design guidelines based on the element selected and the type of water fed to the RO/ROSC system. These guidelines apply to:

- Recommended recovery for each element
- Maximum feed flow to each element
- Maximum permeate flow from each element
- Minimum concentrate flow from each element

These guideline values are aligned with specific feed water types; thus a choice of feed water type is effectively a choice of which guideline to use.

The Water Types and Subtypes used in WAVE are shown in the Table 1 below. For RO/NF/ROSC, the SDI (silt deposition index) is a key differentiator.

Table 2. WAVE Water Types and Subtypes visible in RO/NF/ROSC.

Source Water	Subtype
RO/NF Permeate	SDI <1
Softened	With DUPONT™ UF, SDI < 2.5
	SDI<3
Municipal	With DUPONT™ UF, SDI < 2.5
	SDI<3
	SDI<5
Well water	With DUPONT™ UF, SDI < 2.5
	SDI<3
Surface Water	With DUPONT™ UF, SDI < 2.5
	SDI<3
	SDI<5
Seawater	With DUPONT™ UF, SDI < 2.5
	With membrane pretreatment, SDI<3
	With conventional pretreatment, SDI<5
Wastewater	With DUPONT™ UF, SDI < 2.5
	With membrane pretreatment, SDI<3
	With conventional pretreatment, SDI<5

2.3 Defining the Feed Water Composition for UF

There are three ways to specify water compositions in WAVE for UF.

WAVE does not require a complete feed water composition to model UF. However, there are a few points to keep in mind:

- If no ions are specified in the feed water composition, WAVE would ask for mineral acid and alkali doses for CEB and CIP in mg/L. However, if the composition of even a few ions are specified, WAVE would request mineral acid and alkali doses in terms of target pH values.
- If there are RO or IX processes downstream of the UF process, then WAVE would ask for a charge-balanced feed water composition.

2.3.1 Specification of Feed Water for UF design

The amount of each component can be specified as shown below.

The suggested order is:

1. From the Feed Water tab, select the water type.
2. Enter the solid content properties (NTU, TSS, SDI) and the organic content (TOC).
3. Enter the temperature values and pH.
4. Adjust the pH value using ¨Adjust pH¨ button

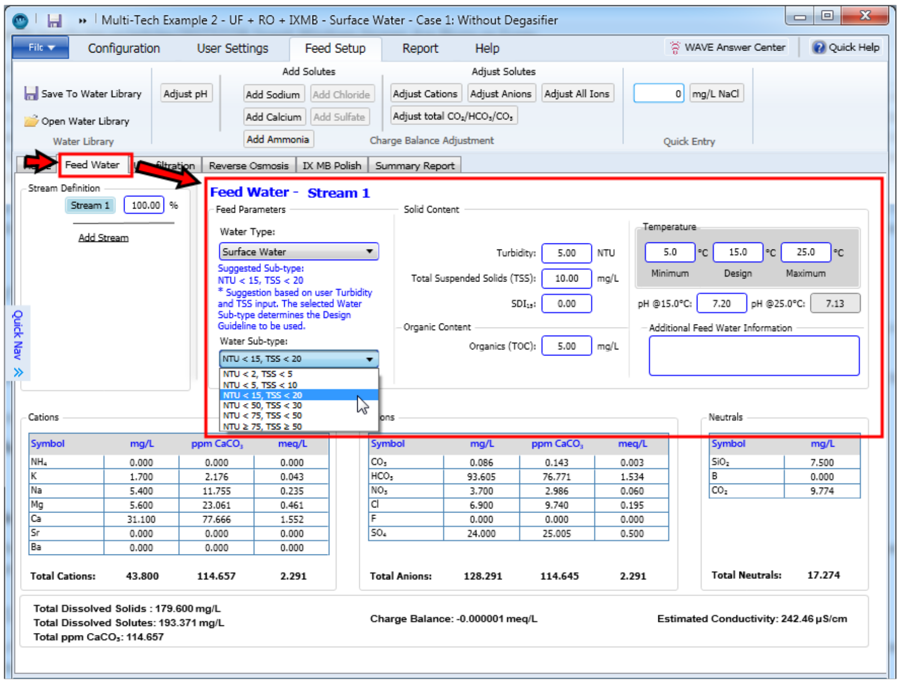


Figure 31. Entry of UF specific feed composition

Notes:

- WAVE limits the minimum temperature to 1°C and the maximum temperature in the Feed Water temperature entry fields to 40°C for UF.
- WAVE does not have a correlation between the Turbidity, SDI and Total Suspended Solids (TSS) fields. The user is expected to put in the correct values for each field.

2.3.2 Quick Entry of NaCl concentration only

To enter a feed water stream containing only Na and Cl, the Quick Entry methods described below should be followed.

1. In the 'Feed setup' tab put an appropriate value of Total Dissolved Solids in the "mg/L NaCl" field
2. Click on the "mg/L NaCl" button. This populates Na and Cl entries

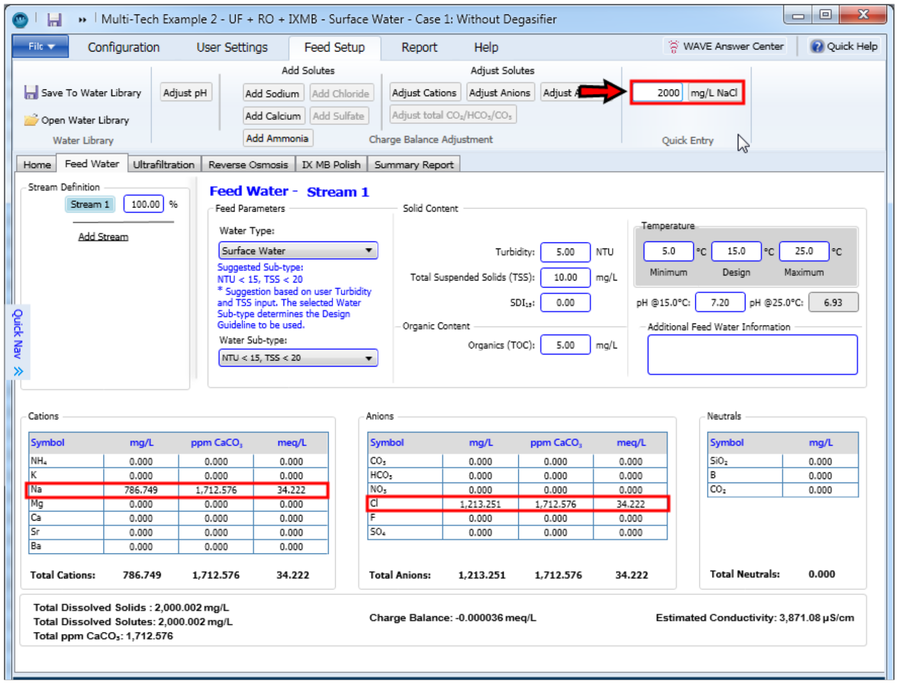


Figure 32. Quick entry of NaCl composition

Notes:

- The water composition entered through the Quick Entry method is always charge balanced.
- Using the Quick Entry method immediately clears the Cations, Anions and Neutrals tables.
- In WAVE, one can clear all the cells by putting in "0 mg/L" in the Quick Entry field.

2.3.3 Detailed Ionic Content

The amount of each dissolved component can be specified. . The suggested order is:

1. From the Feed Water tab, select the water type.
2. Enter the solid content properties (NTU, TSS, SDI) and the organic content (TOC).
3. Enter the temperature values and pH.
4. Enter the cations, anions and neutrals.

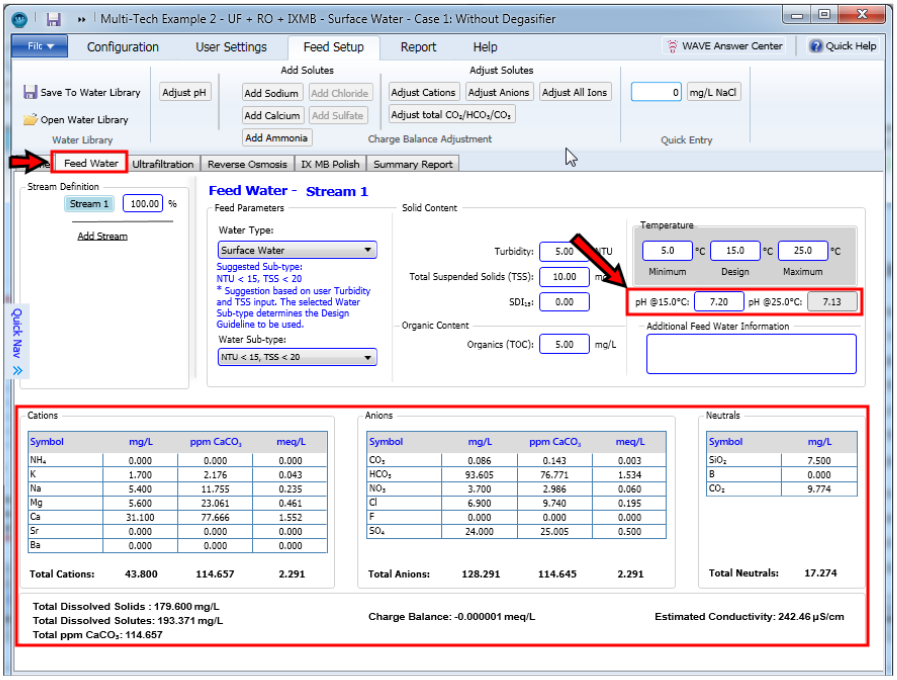


Figure 33. Detailed entry of the ionic feed composition

Notes:

- WAVE limits the minimum temperature to 0°C and the maximum temperature to 100°C. Warnings will be generated in the Feed Water temperature entry fields based on the water treatment options that were selected.
- Populating the HCO3/CO3 field automatically populates the HCO3/CO3/CO2 fields.
- The definition of TDS depends on the water treatment option. In RO, TDS refers to “Total Dissolved Solids” and excludes dissolved CO2. In the IX modules, TDS refers to “Total Dissolved Solutes” and includes dissolved CO2.

2.4 pH Specification

In WAVE, pH is defined as $-\log_{10}$ of the H^+ concentration (in mol/L). For a solution of fixed composition, the H^+ concentration and thus the pH will be a function of the temperature due to the temperature dependence of equilibrium constants. As an example, the ionization constant of water is a function of temperature, with pK values of 14.94, 14.00, and 13.26 at 0, 25, and 50 °C, respectively. This implies that the pH of pure water is 7.47, 7.00, and 6.63 at 0, 25, and 50 °C, respectively. The equilibrium constants for carbonate alkalinity reactions

$$(H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+)$$

and ammonia reactions

$$(NH_3 + H^+ \leftrightarrow NH_4^+)$$

are also functions of temperature. Thus the concentrations of all of these species will be a function of pH and temperature.

In WAVE, when pH is given as an input, it is assumed that this corresponds to the H^+ concentration at the design temperature. If the solution is charge balanced by adding solutes or adjusting solutes, the H^+ concentration at the design temperature is fixed. Only if the solution is charged balanced by adjusting pH will the H^+ concentration at the design temperature vary. After a solution is charge balanced, WAVE displays on the feed water screen the pH at both the design temperature and at a standard temperature of 25 °C.

Once you have a charge balanced solution at the design temperature, if a computation is run at a different temperature then WAVE will automatically determine the correct pH for that temperature and adjust the water chemistry appropriately. This occurs when the user selects a computation temperature on the RO screen or the summary screen other than the design temperature (for example, minimum or maximum).

In some cases the pH is known at one temperature, but the design is to be run at a substantially different temperature. This commonly occurs in condensate polishing, where the pH at 25 °C is known but the system design temperature is substantially higher. When this situation occurs, the following protocol is recommended to get the most accurate results.

- Initially determine the water composition at the temperature where the pH is known.
  - Enter the known pH.
  - Enter the known pH temperature (25 °C) as the design temperature.
  - Enter the remaining constituents of the feed water.
  - Charge balance the solution using one of the Add Solutes or Adjust Solutes options.
- Determine the water composition at the design temperature
  - Enter the actual design temperature
  - Charge balance the solution using the Adjust pH option. The total moles of related species will be held constant, but all of the equilibrium constants will be recomputed for the new temperature and then the H^+ concentration and thus the pH will be adjusted to charge balance the solution.

As an example, assume that the pH of an ammonia solution is known to be 9.50 at 25 °C. Inputting those values and using the Add Ammonia option gives a total NH_3/NH_4^+ concentration of 1.615 mg/L as NH_4^+. If a design temperature of 55 °C is entered, using the Adjust pH option will give a pH at that temperature of 8.65. Note that the pH at 25 °C is correctly displayed as 9.50.

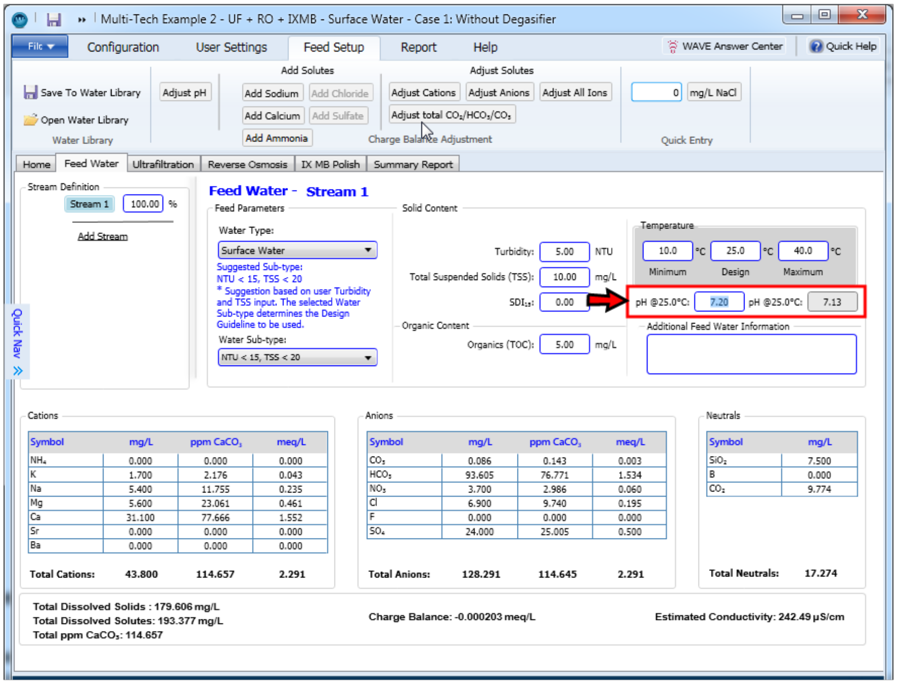


Figure 34. pH entry

2.5 Condensate Polishing Additional Parameters

In case of Condensate Polishing Feed Water tab allows to include additional parameters specific for this technology as Amines and CRUD: pH Control anions, 1,2-diaminoethane, 2-amino-2-methyl-1-propanol, 3-methoxypropylamine, 5-aminopentanol, ammonia, cyclohexylamine, ethanolamine, morpholine.

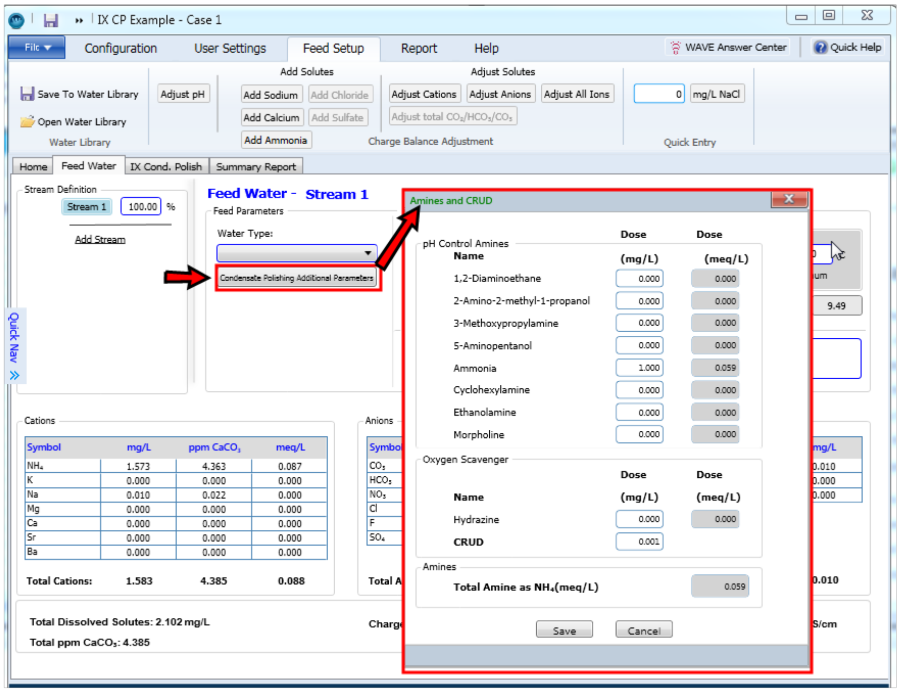


Figure 35. Detailed entry of the condensate polishing additional parameters

Note:

- The Condensate Polishing Popup window will automatically estimate the Total Amine content in the feed water.

2.6 Balancing the Feed Water

In WAVE, the feed water must be charge balanced before the user is allowed to either simulate or specify the system design. There are several paths for charge balancing the feed water:

2.6.1 Charge Balancing by Addition of Specific Solutes

In WAVE, one can perform charge balancing by adding the following ions

- Cations: Sodium, Calcium, Ammonia
- Anions: Chloride, Sulfate

Depending on whether the specified water has a net positive (requires anions) or negative (requires cations) charge, WAVE would display buttons to add the appropriate ions (Figure 36 and Figure 37). The user should click on the appropriate button. The Charge Balance value will drop to a very small number.

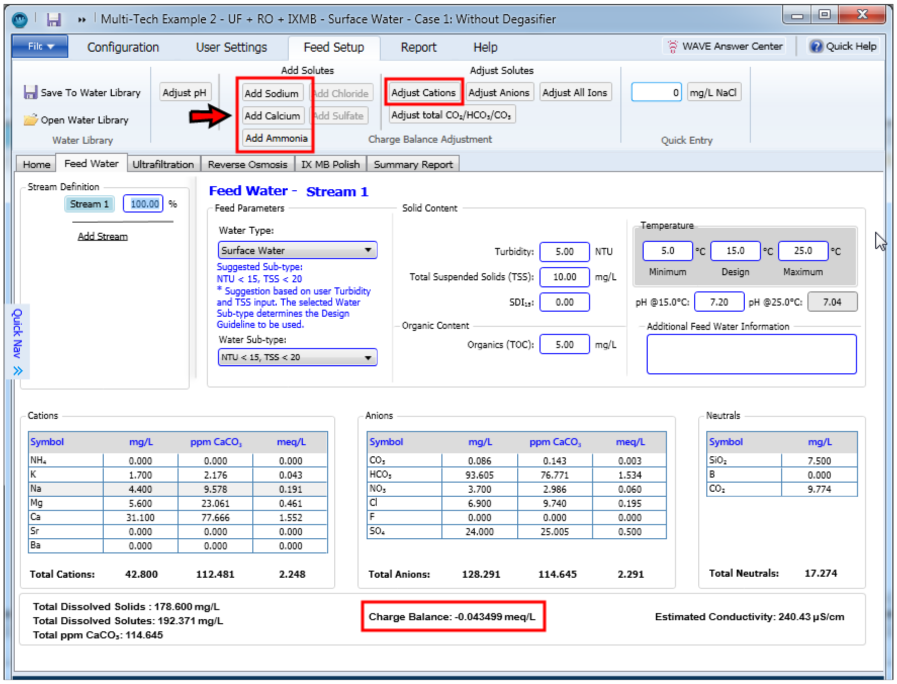


Figure 36. Charge balancing a stream by adding cations

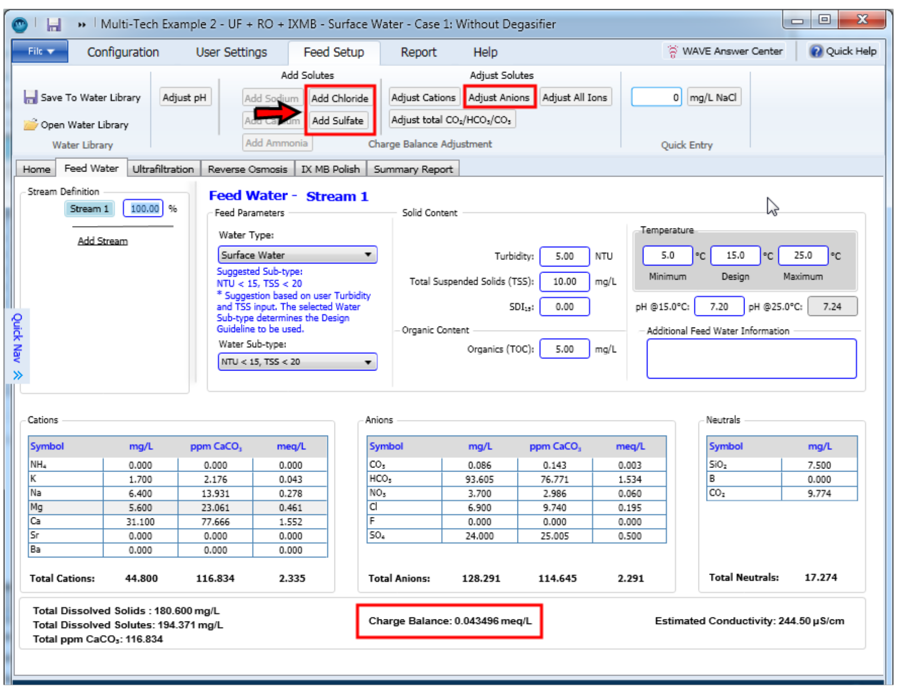


Figure 37. Charge balancing a stream by adding anions

Notes:

- Charge balancing with addition of solutes does not affect the ammonia equilibrium
- The buttons used for Charge Balancing (Adjust pH, Adjust Solutes, Add Solutes) would be grayed out under most circumstances. However, after several attempts, the buttons are still not greyed out, it means that WAVE is as close to charge balance as possible. Users can then proceed with the design.
- This method is the simplest charge balance method and is commonly used.

2.6.2 Charge Balancing by Adjustment of Solute Compositions

Another method to balance the feed charge in WAVE is by adjusting solutes. This would involve proportional adjustment of cations, anions or both. Three options are given in WAVE:

1. Cations: NH4, K, Na, Mg, Ca, Sr, Ba
2. Anions: CO3, HCO3, NO3, Cl, F, SO4
3. Both (Cations and Anions)

As shown, the user can pick the appropriate option.

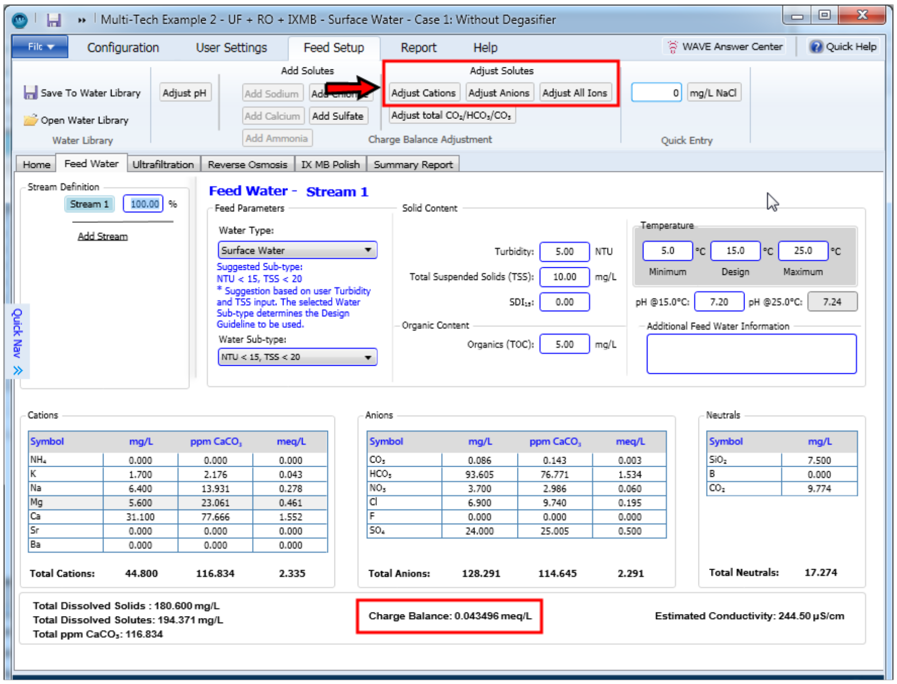


Figure 38. Charge balancing in WAVE by adjusting solutes

Notes:

- Charge balancing with addition of solutes does not affect the pH
- The carbonate equilibrium is affected by “Adjust Anions” and “Adjust All Ions” options.
- The ammonium equilibrium may be affected by “Adjust Cations” and “Adjust All Ions” options.
- The buttons used for Charge Balancing (Adjust pH, Adjust Solutes, Add Solutes) would be grayed out under most circumstances. However, after several attempts, the buttons are still not greyed out, it means that WAVE is as close to charge balance as possible. Users can then proceed with the design.

2.6.3 Charge Balancing the $CO_2/HCO_3/CO_3$ composition for a given feed pH

The WAVE calculation engine would determine the equilibrium CO_3/CO_2 composition given a feed pH using proprietary equations. Thus the composition of the three species can be adjusted to achieve charge balance. The user can click on "Adjust total CO_2/ HCO_3/CO_3" as shown.

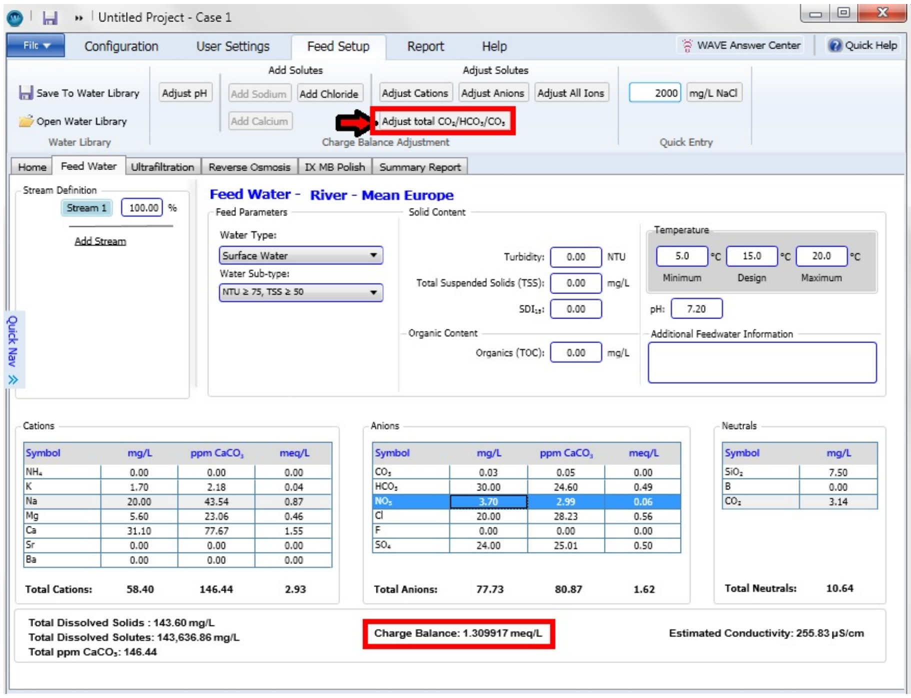


Figure 39. Balancing the $CO_2/HCO_3/CO_3$ composition for a given feed pH

Notes:

- WAVE automatically calculates the equilibrium $CO_2/HCO_3/CO_3$ composition given either the HCO_3 or CO_3
- The carbonate equilibrium in the feed water is affected by pH, temperature and TDS. Thus if the user changes the amount of other ions by a large extent, the carbonate equilibrium will be affected.

2.6.4 Charge Balancing by Adjusting the pH

The specific composition of several species (e.g. carbonates, ammonia) is affected by pH. Thus by adjusting pH, users can charge balance the water. This is done in WAVE by clicking on the "Adjust pH" button as shown below.

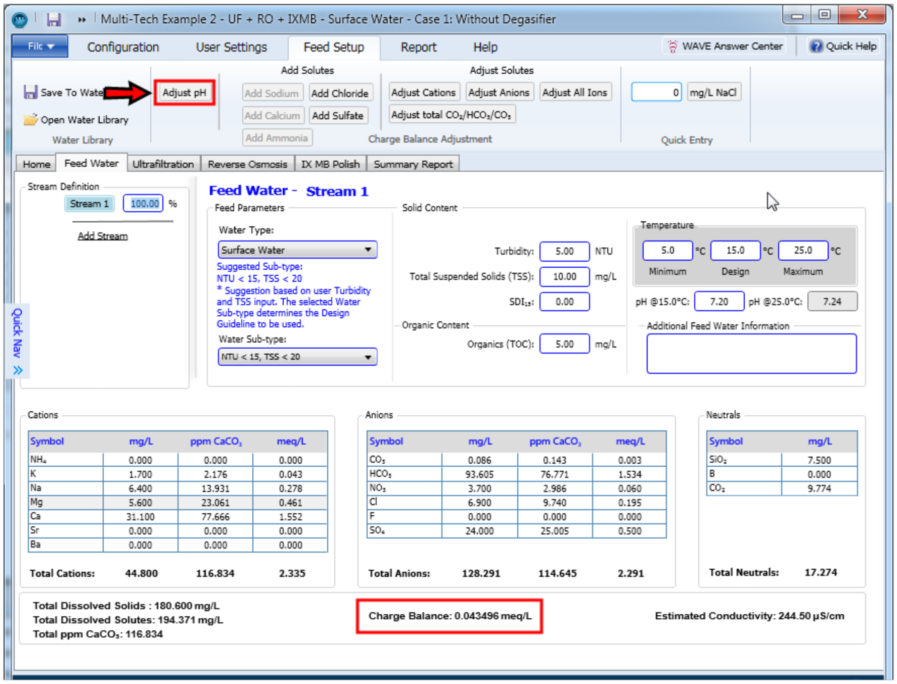


Figure 40. Charge balance by adjusting pH

2.7 Import from the Water Library

If a water profile is available in the Water Library, then it can be copied to the Feed Water Tab using the following steps:

1. From the Feed Water tab, click on “Open Water Library” and click on the dropdown list.

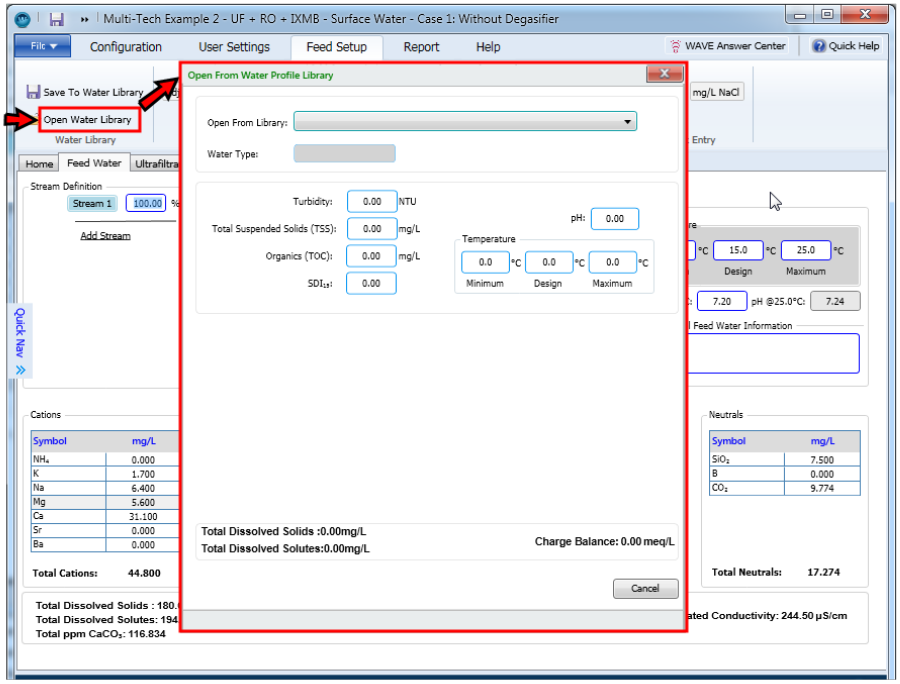


Figure 41. Accessing the Water Library from the Feed Water tab and opening the dropdown for water profiles

2. Select a water profile from the drop down list and click on “Copy to Feed Water”

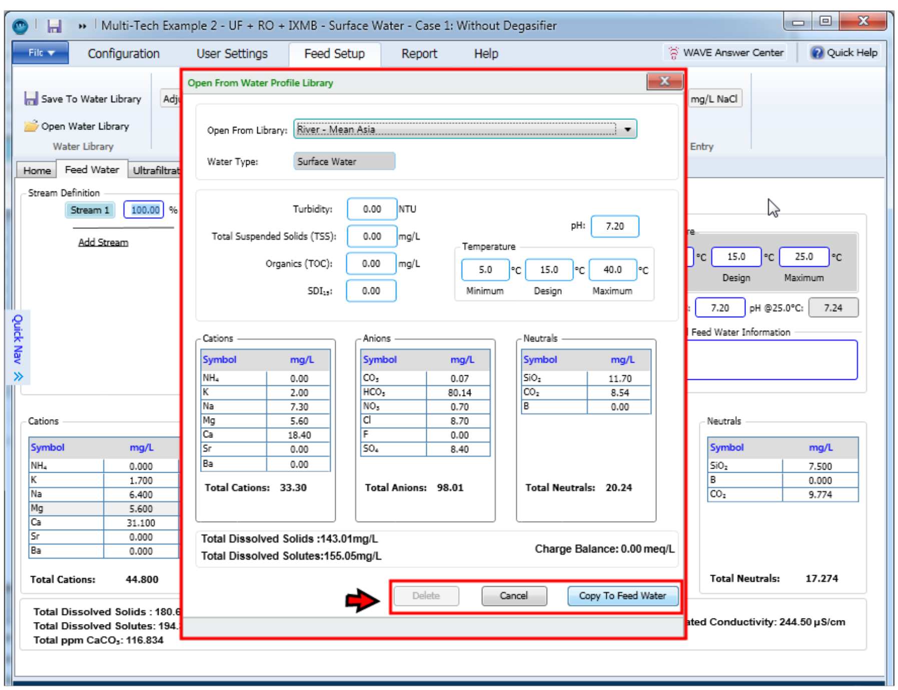


Figure 42. Accessing the dropdown for water profiles

3. The water profile is now copied over to the Feed Water Tab.

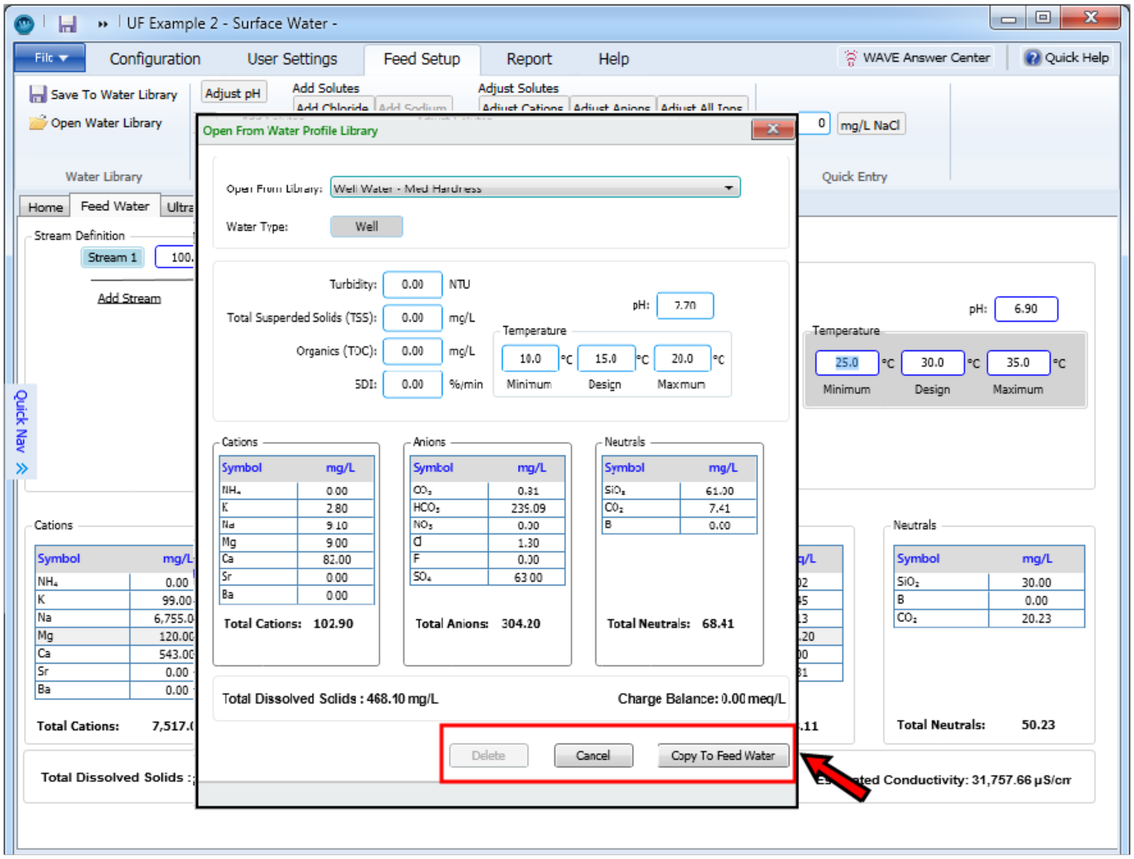


Figure 43. Transferring the water profile to the Feed Water screen

2.8 Chemical Addition and pH Adjustment to the UF feed

WAVE enables the following modifications (from what was entered in the Feed Water Tab) to the UF feed stream:

2.8.1 pH Adjustment of UF Feed

This is done by following the steps below:

1. Click on the "Add Chemicals/Degas" button. The Chemical Adjustment Popup Window will appear).

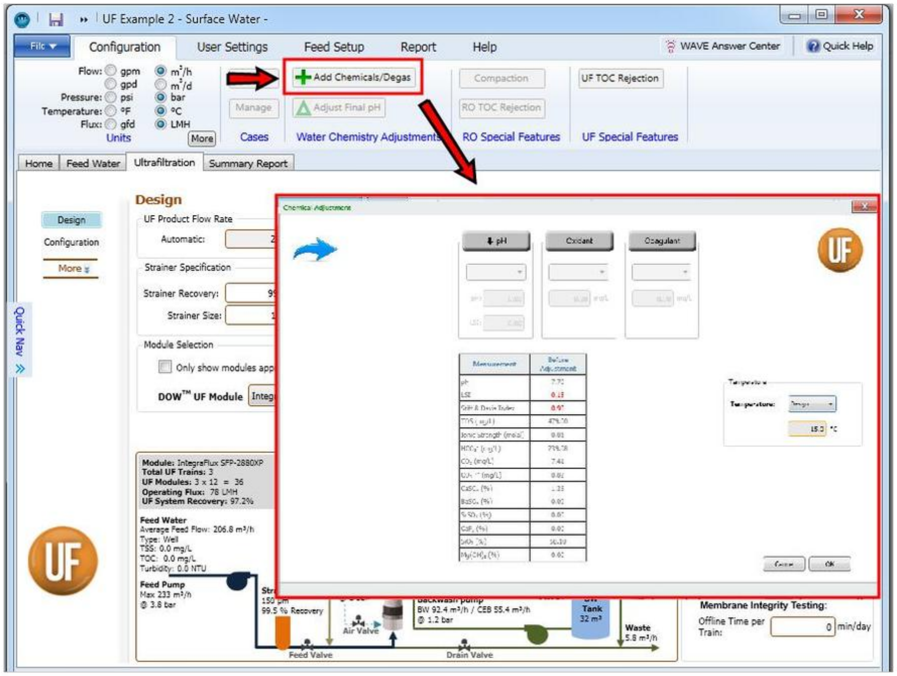


Figure 44. Opening "Chemical Adjustment" window

2. Click on the "pH" button to enable pH reduction. An acid addition line (named "ACID") would automatically appear in the UF System Diagram and an additional column (named "After pH") would appear in the table inside the Chemical Adjustment Popup Window.Figure 47. Feed pH specification for UF

3. Click on the dropdown arrow and select an acid. The selected acid, along with its concentration in the ACID stream, would be shown in the UF System Diagram.

4. Specify a pH. The values in the "After pH" column in the in the table inside the Chemical Adjustment Popup Window would be updated. In addition, the concentration of the acid in the UF stream needed to achieve the specified pH is displayed in the UF System diagram.

5. Click “OK”.

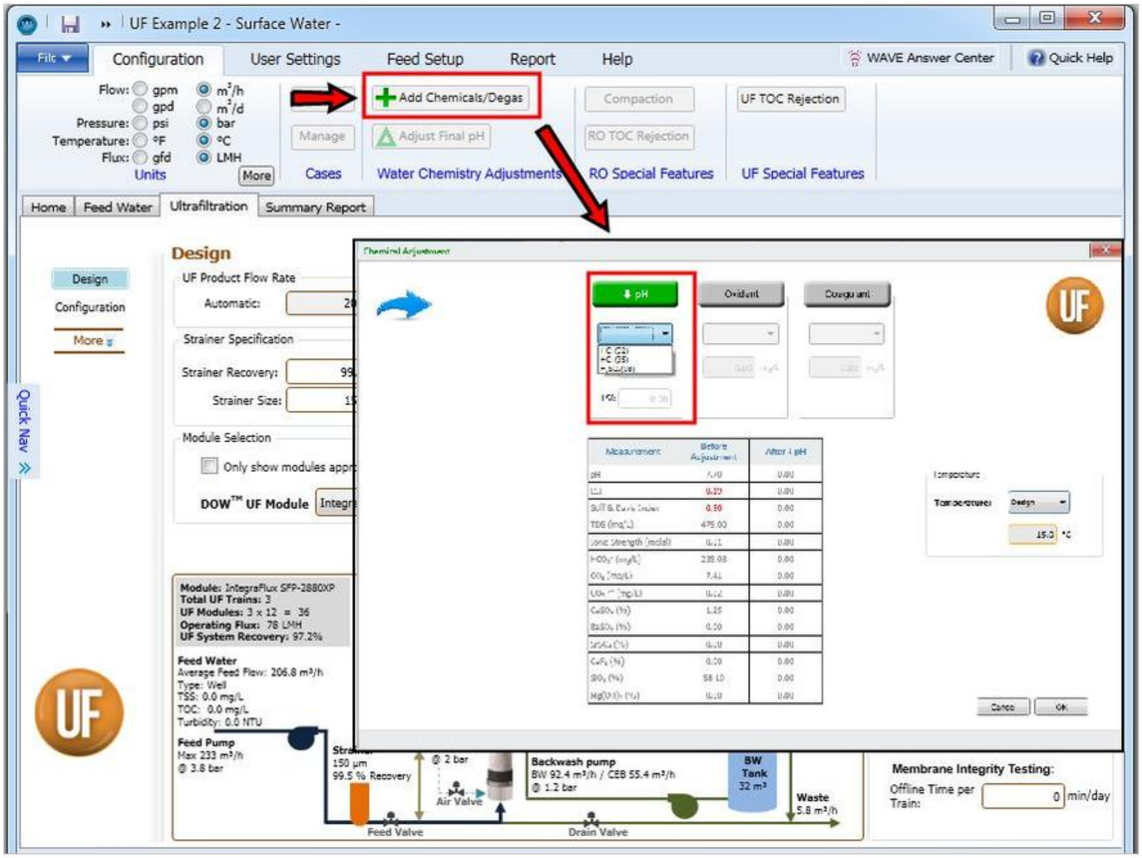


Figure 45. Feed pH specification for UF

6. The tool allows also adding Oxidant and Coagulant.

Note: The acid is selected from the list of chemicals defined by the user as shown in Sections Chemical Library and Adding a New Chemical.

2.8.2 Temperature Adjustment of Feed

This is done by following the steps below:

1. Click on the "Add Chemicals/Degas" button to get the Chemical Adjustment Popup Window.
2. Click on the dropdown box in the Temperature Specification Box. The following options appear: Minimum, Design, Maximum and Specify
3. Select "Specify" and enter the temperature of interest.
4. Click "OK".

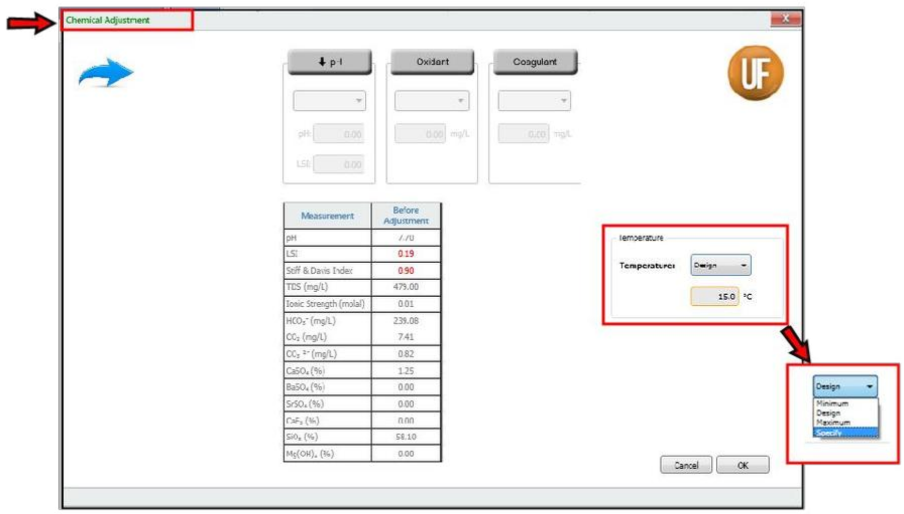


Figure 46. Specification of feed temperature for UF in WAVE

2.8.3 Oxidant Addition to the UF Feed

This is done by following the steps below:

1. Click on the "Add Chemicals/Degas" button. The Chemical Adjustment Popup Window will appear.
2. Click on the "Oxidant" button to enable oxidant addition. An oxidant addition line (named "OXIDANT") would automatically appear in the UF System Diagram.
3. Click on the dropdown arrow and select an oxidant. The selected oxidant, along with its concentration in the OXIDANT stream, would be shown in the UF System Diagram.
4. Specify the target concentration of the oxidant in the UF feed stream. The target concentration of the oxidant in the UF stream is displayed in the UF System diagram.

5. Click “OK”.

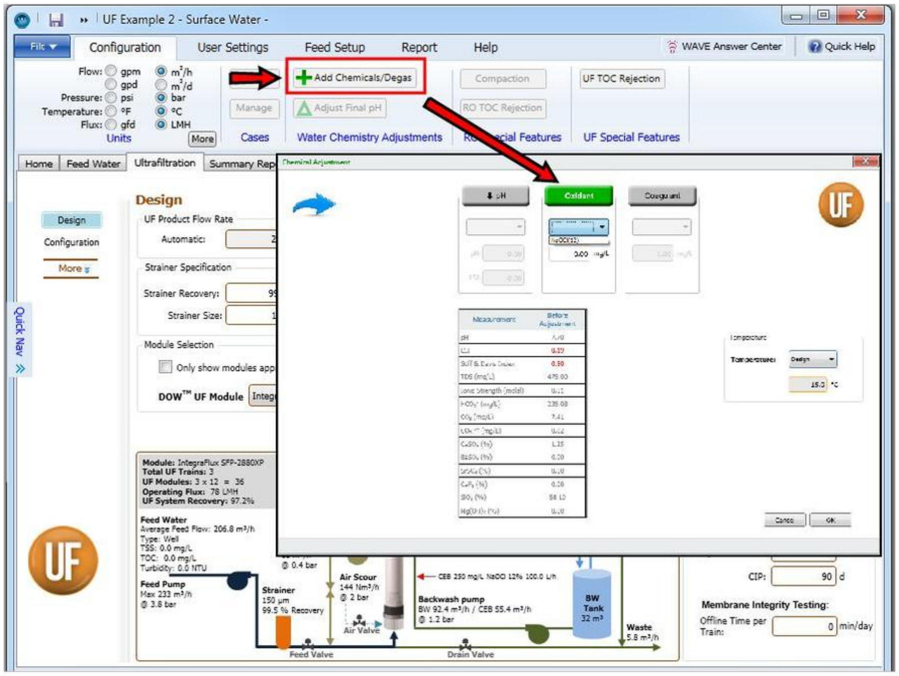


Figure 47. Specification of Oxidant addition for UF in WAVE

Notes:

- The oxidant is selected from the list of chemicals defined by the user as shown in Sections Chemical Library and Adding a New Chemical.
- The user can add a coagulant from any of the UF windows by clicking on the “Add Chemical/Degas” option.

2.8.4 Coagulant Addition to the UF Feed

This is done by following the steps (as shown in Figure 48):

1. Click on the "Add Chemicals/Degas" button. The Chemical Adjustment Popup Window will appear.
2. Click on the "Coagulant" button to enable oxidant addition. A coagulant addition line (named "COAGULANT") would automatically appear in the UF System Diagram.
3. Click on the dropdown arrow and select a coagulant. The selected coagulant, along with its concentration in the COAGULANT stream, would be shown in the UF System Diagram.
4. Specify the target concentration of the coagulant in the UF feed stream. The target concentration of the coagulant in the UF stream is displayed in the UF System diagram.
5. Click "OK".

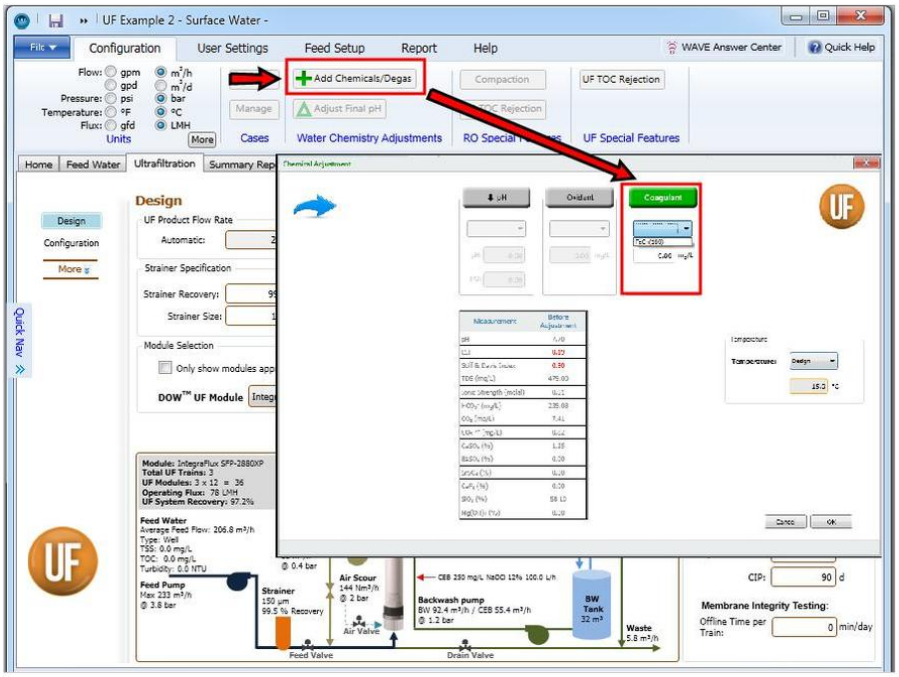


Figure 48. Specification of Coagulant addition for UF in WAVE

Notes:

- The coagulant is selected from the list defined by the user as shown in Sections Chemical Library and Adding a New Chemical.
- The user can add a coagulant from any of the UF windows by clicking on the "Add Chemical/Degas" option.

2.9 Mixing Feed Streams

By default, WAVE always defines a feed stream ("Stream 1") regardless of whether or not a process was selected. However, WAVE provides a possibility for generating a stream combined from several streams.

2.9.1 Adding a Stream

To add another stream in WAVE:

1. From the Feed Water tab, click on "Add Stream".

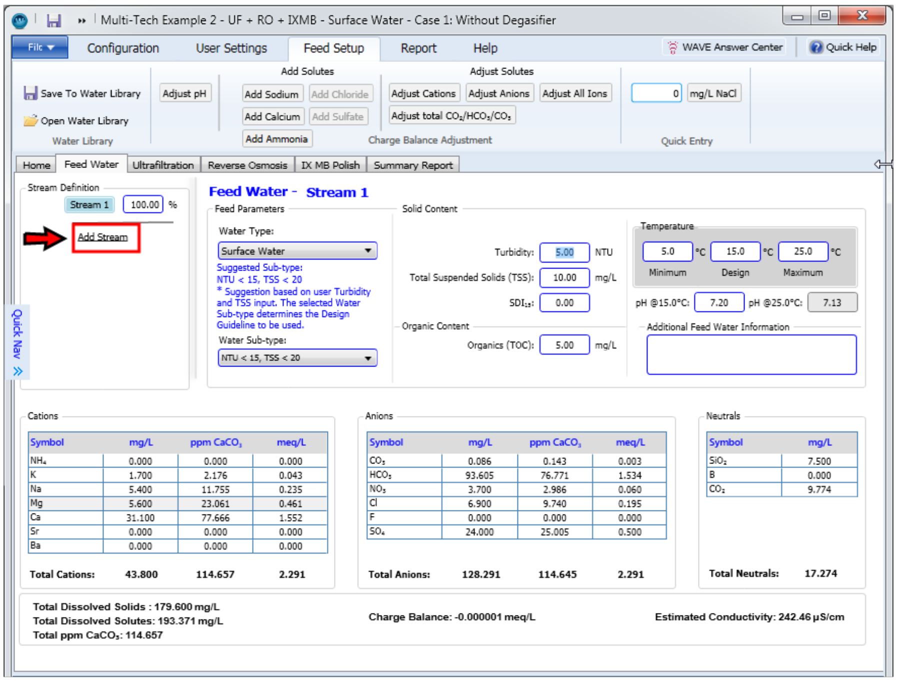


Figure 49. Adding a stream from a different water source

2. Specify the fraction (s) of the two (or more) feed streams which would be blended. The sum of the fractions should always sum up to 100 %.

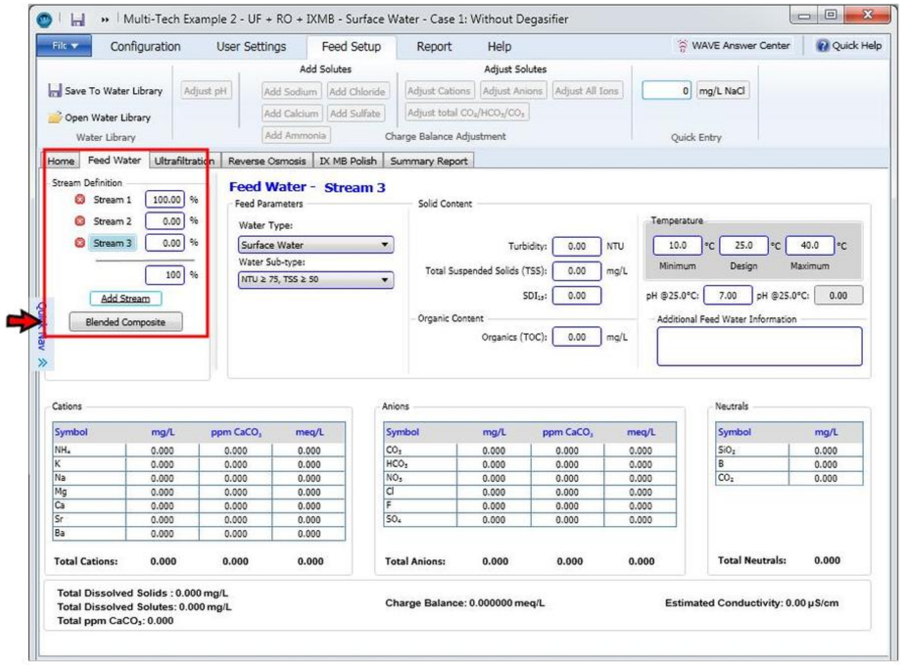


Figure 50. Blending feed water streams in WAVE

3. Click on "Blended Composite"

Notes:

- By default a new feed stream is not blended with the pre-existing feed stream. While "Stream 2" is selected, the user can specify its composition or open the Water Library to load the water.
- As soon as the 'Blended Composite' button is clicked, the combined water type is labeled 'Blended Water'. WAVE would mix the appropriate ionic content, solid content, TOC content and also estimate the pH and temperature.

2.9.2 Removing Feed Streams

To remove streams, the user would click on Red icon. The stream will disappear.

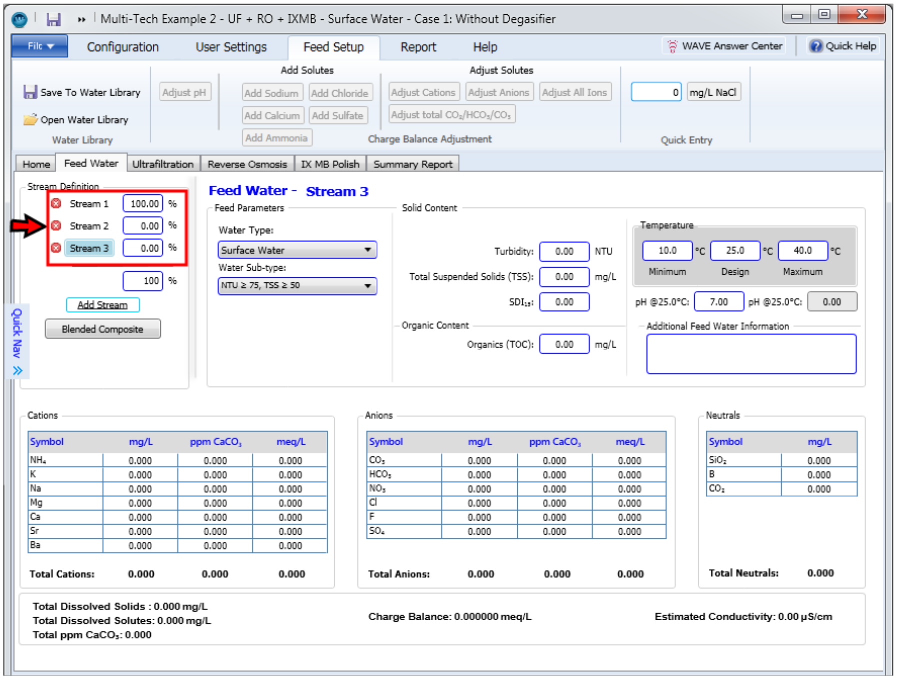


Figure 51. Deleting a stream in WAVE

Notes:

- When a stream is deleted (when there are more than two streams), the fractions of the remaining streams would not be recalculated automatically. The user would have to recalculate the fractions.
- When a stream is deleted, the combined stream is no longer named 'Composite'.

3 Ultrafiltration

3.1 UF System Specification in WAVE

The Ultrafiltration system design in WAVE is a powerful tool that allows sizing of new systems or evaluating the performance of existing ones. In order to design a new Ultrafiltration system it is important to understand the main inputs needed to help get an accurate and optimized design. These inputs include information about the feed water source (e.g., municipal, seawater, wastewater, well water or surface water), quality, temperature range and required feed flow or net plant output. On the other hand, the final application of the project is of interest, as in the case of drinking water applications, specific DUPONT™ UF modules must be used.

For a given feed water type and quality, the appropriate design guidelines must be applied. These design guidelines have been created based on extensive experiences and references in similar waters. The design guidelines include suitable operating flux, duration of the filtration cycles or frequency of the chemical cleanings.

Once all this information is introduced in the system design software, it will populate a detailed Ultrafiltration System Design report, which includes a general process flow diagram, module selection, sizing and quantity of trains, sizing of water and chemical tanks, process parameters and sequence tables, as well as estimations for chemical and energy consumption, among others.

UF system specification includes the following steps:

3.1.1 Adding the UF Icon into the WAVE Home Window

The UF Symbol can be dragged and dropped on top of the gray spot to specify a UF process as shown in. If the gray spot is not visible, simply dragging the UF icon between the two large blue arrows will make the gray spot visible.

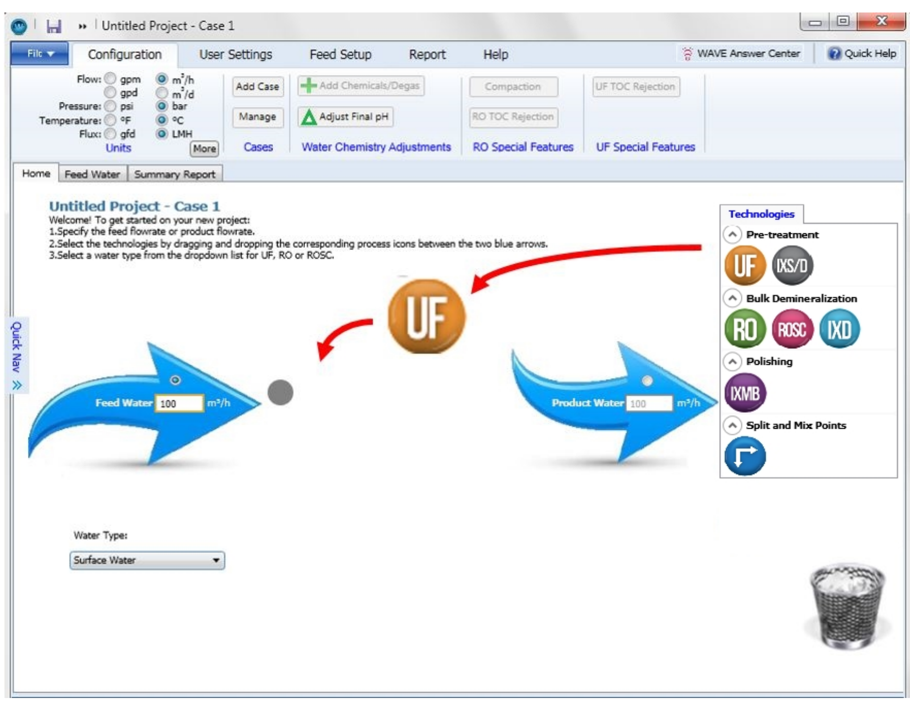


Figure 52. Dragging and dropping UF icon

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January 2020

3.1.2 Removing the UF Icon

There are two ways to remove the UF process icon:

1. Dragging and dropping the icons into the picture of the waste bin

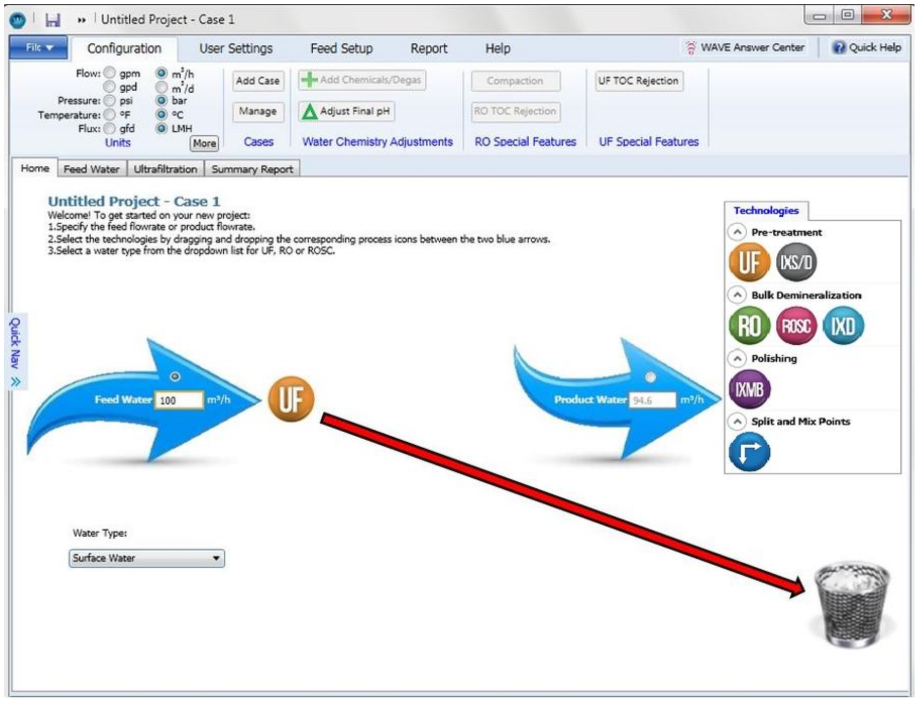


Figure 53. Dragging and dropping the icons into the picture of the waste bin

2. Right-clicking on the icon in question and selecting "Delete"

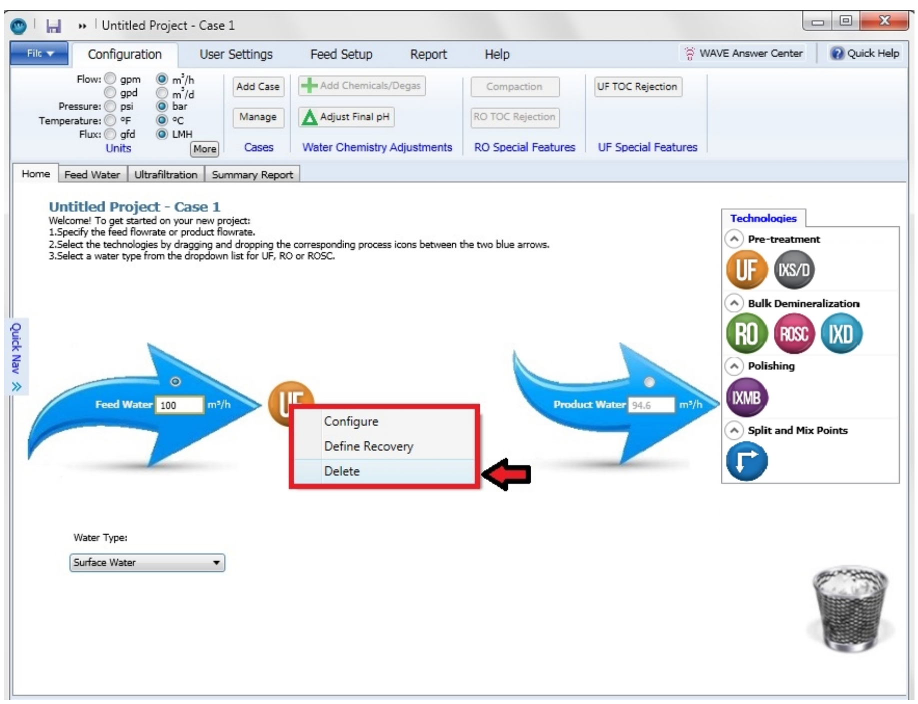


Figure 54. Right-clicking on the icon in question and selecting "Delete"

3.1.3 Defining the Feed Water Flowrate and Recovery

Feed and Product water flowrates should be specified using the text boxes in the middle of the blue arrows. First, Feed or Permeate flow option should be selected using the radio button in the upper part of the arrow, later the flowrate can be specified.

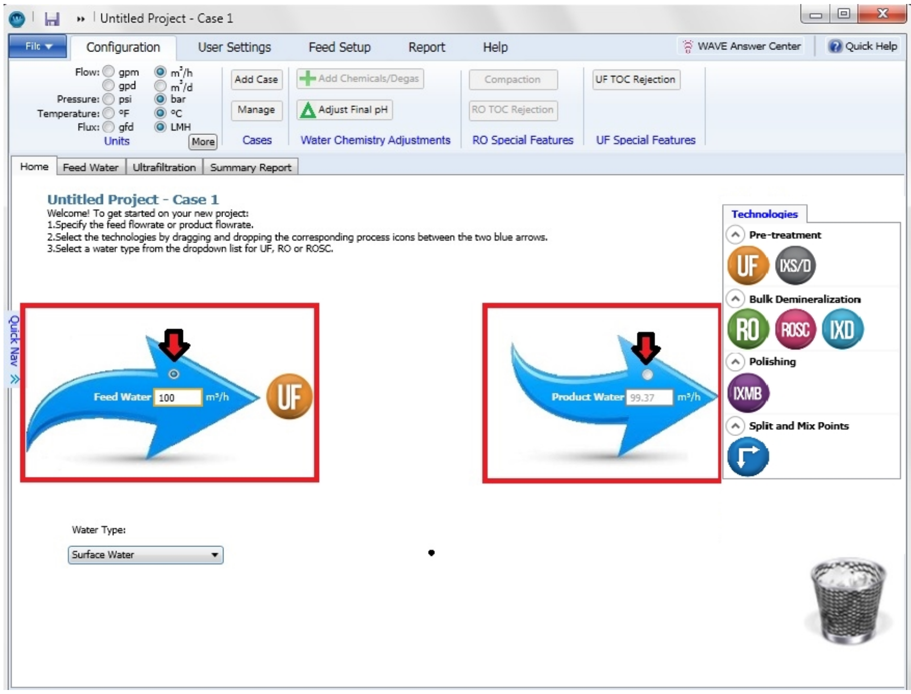


Figure 55. Definition of feed or product flow for a UF system

Notes:

- WAVE would display a warning if the Feed or Product flowrates are specified as 0 or a negative number
- Given a feed water flowrate, WAVE would calculate a product flowrate based on a default recovery. Given a product water flowrate, WAVE would calculate a feed flowrate based on a default recovery. For UF, a default recovery of 95% is used.

WAVE does give the user the possibility of defining a recovery that defines feed/product flow if product/feed flow is known. This is done by:

1. Right-clicking on the UF icon
2. Selecting “Define Recovery”
3. Entering the desired recovery

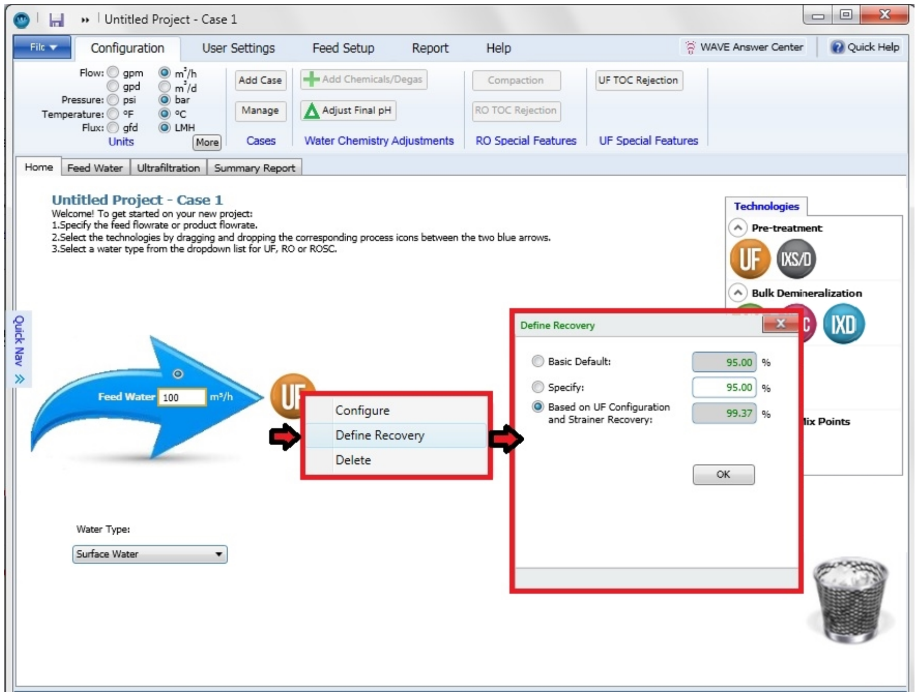


Figure 56. Definition of recovery for a UF system in the Home page

The default recovery value for UF systems is 95% in WAVE. The recovery defined above is a system recovery and is used– currently based on UF configuration and strainer recovery

3.1.4 Specifying Feed Water Properties

The way to specify the feed water characteristics is described in detail on Section Specification of Feed Water for UF design.

3.1.5 Defining the System Design

Fundamental UF System Design information can be specified on "Design" window.

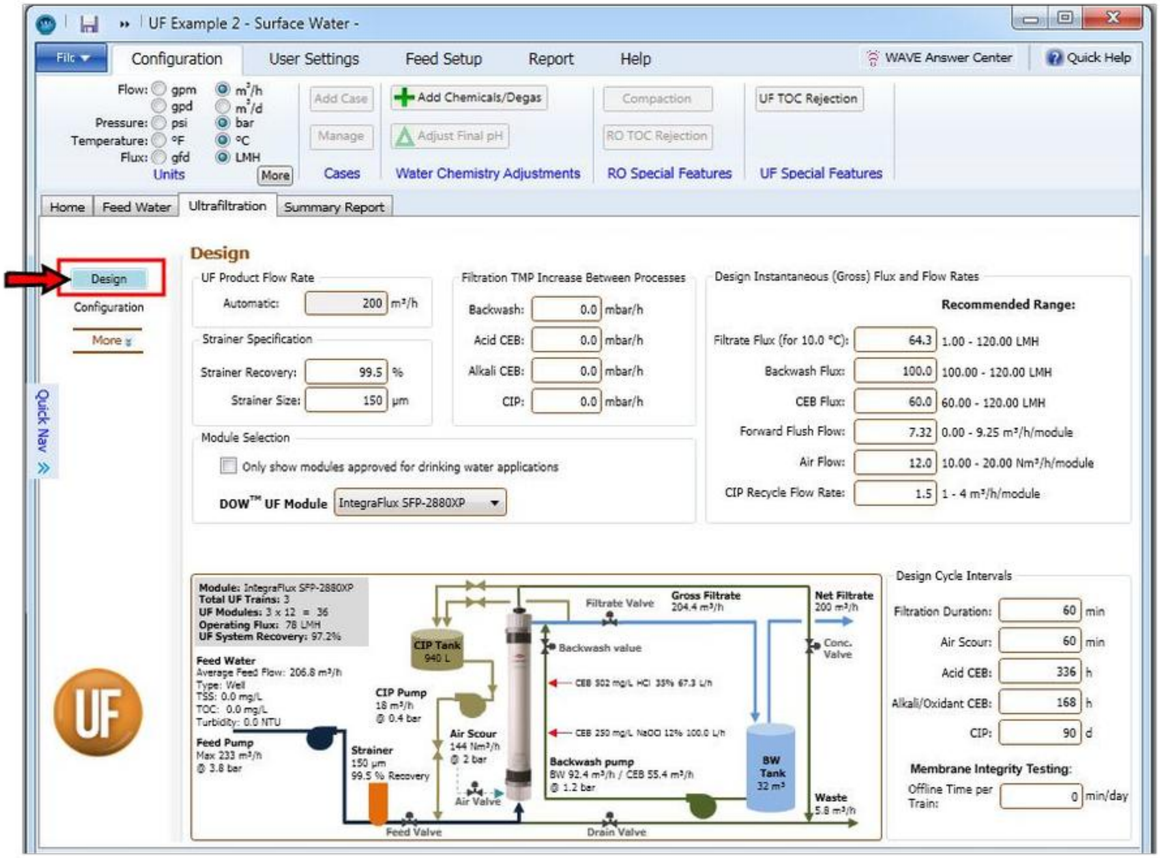


Figure 57. UF Plant Design window

UF Feed Flow Rate

The feed flowrate to the UF is specified by the user at the Home Tab as indicated in Section Defining the Feed Water Flowrate and Recovery.

UF Module Selection

The UF module of interest can be selected from the Design Window. Once the module is selected, the table of Recommended Configurations would be updated.

Drinking water modules are included in the list once the ¨Include drinking water modules¨ box is checked.

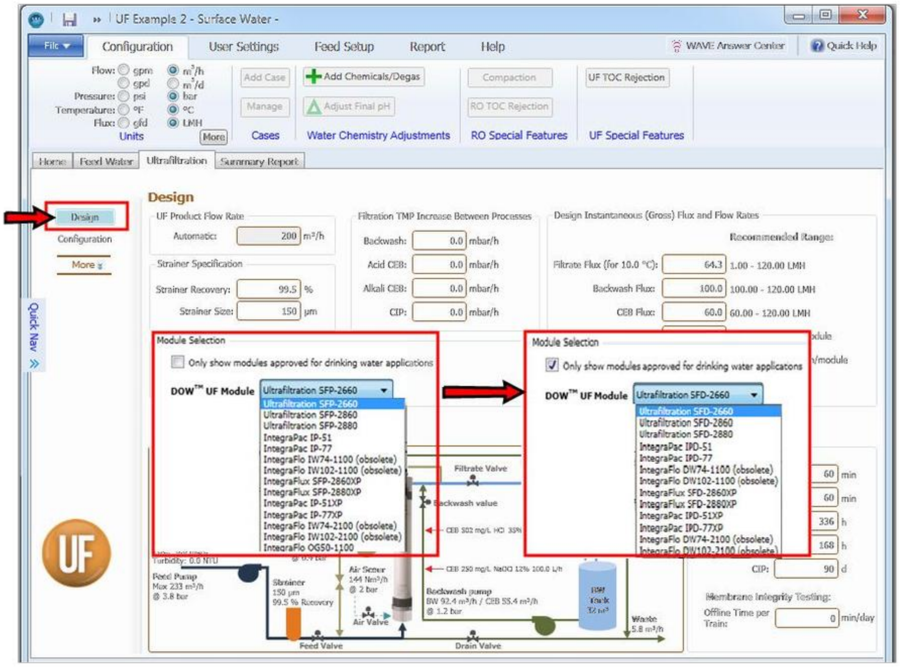


Figure 58. How to select a UF module type

IntegraPac™ Ultrafiltration Skids

A subset of the DW&PS product offerings are the IntegraPac™ products. Sliders depicting the minimum and maximum Skid Sizes would be displayed on the Recommended Configurations table that can be found in the ¨Configuration¨ tab.

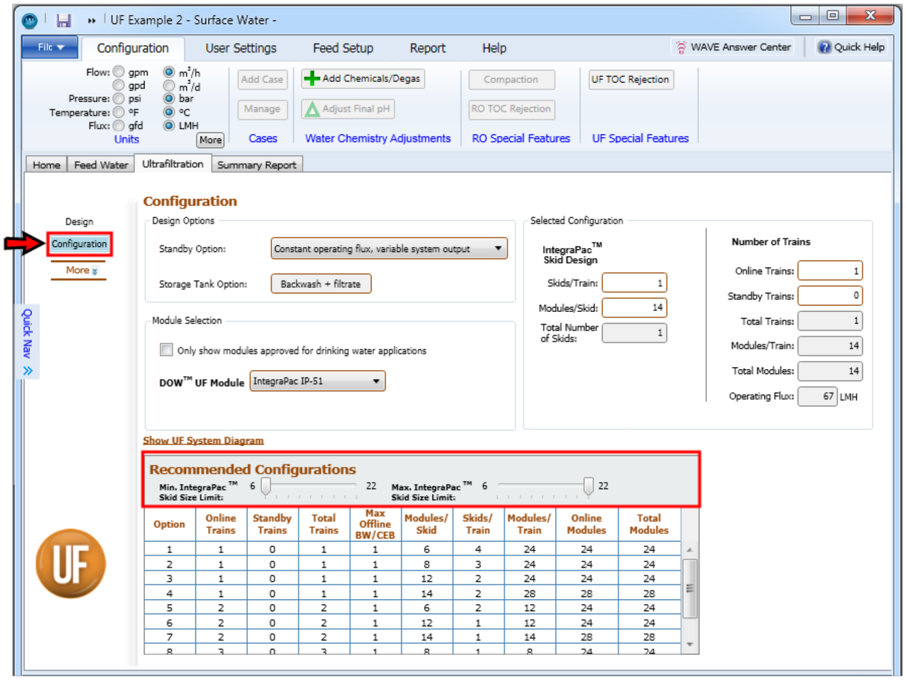


Figure 59. IntegraPac™ sliders in WAVE

Note: WAVE may allow the user to set the Min IntegraPac™ Ultrafiltration Skid Size Limit to be larger than the Maximum IntegraPac™ Skid Size Limit; however, the Recommended Configurations Table would be empty.

If the user enters a number of modules per skid higher than the maximum IntegraPac™ skid size limit (22), a warning message will appear.

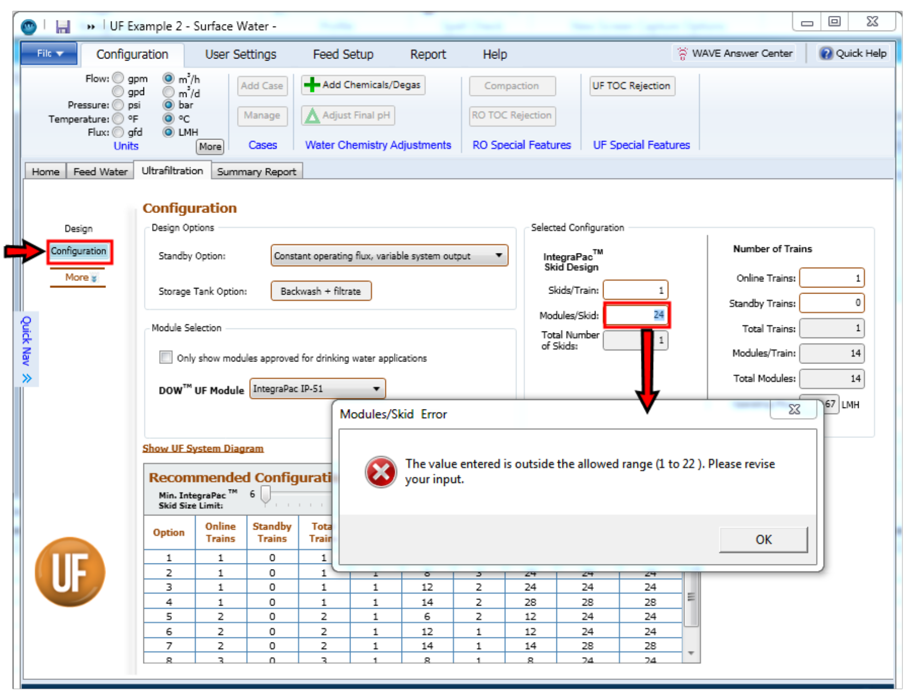


Figure 60. Warning message if the number of IntegraPac™ modules is exceeded

UF Fluxes and Flowrates

WAVE allows the user to set the following values using text entry boxes.

1. Filtrate flux
2. Backwash flux
3. CEB flux
4. Forward Flush flowrate
5. Airflow
6. CIP Recycle flow rate

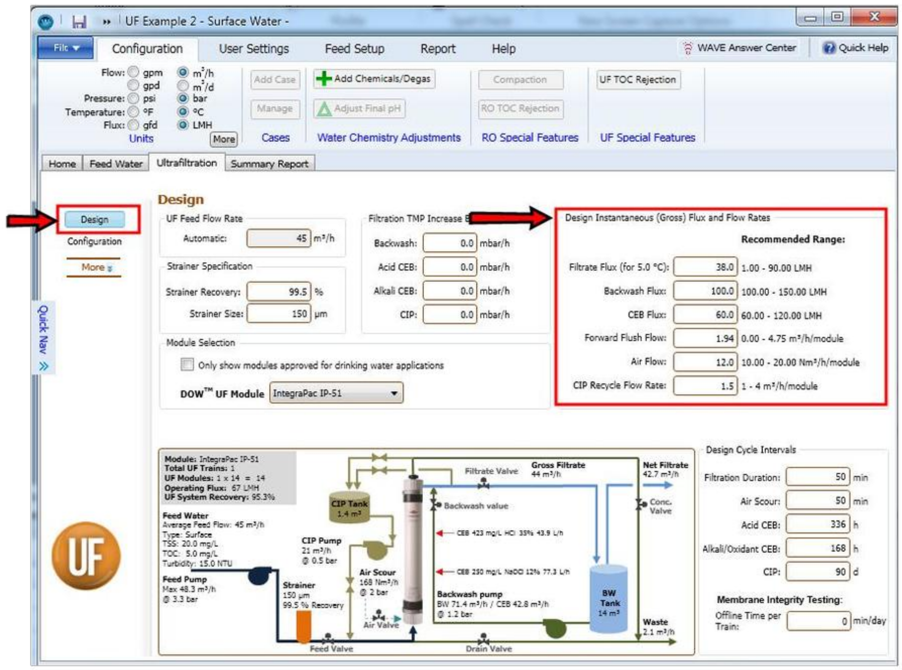


Figure 61. UF Fluxes and Flowrates

Note: WAVE populates the flow rates and fluxes by default based on DuPont Ultrafiltration – General Design Guidelines.

Design Cycle Intervals and Membrane Integrity Testing

WAVE allows the user to set the cycle intervals for each mode in UF using the number entry boxes.

1. Filtration Duration – span before interruptions
2. Air scour – span between each successive incidence
3. Acid CEB– span between each successive incidence
4. Alkali/Oxidant CEB– span between each successive incidence
5. CIP– span between each successive incidence
6. Membrane integrity testing

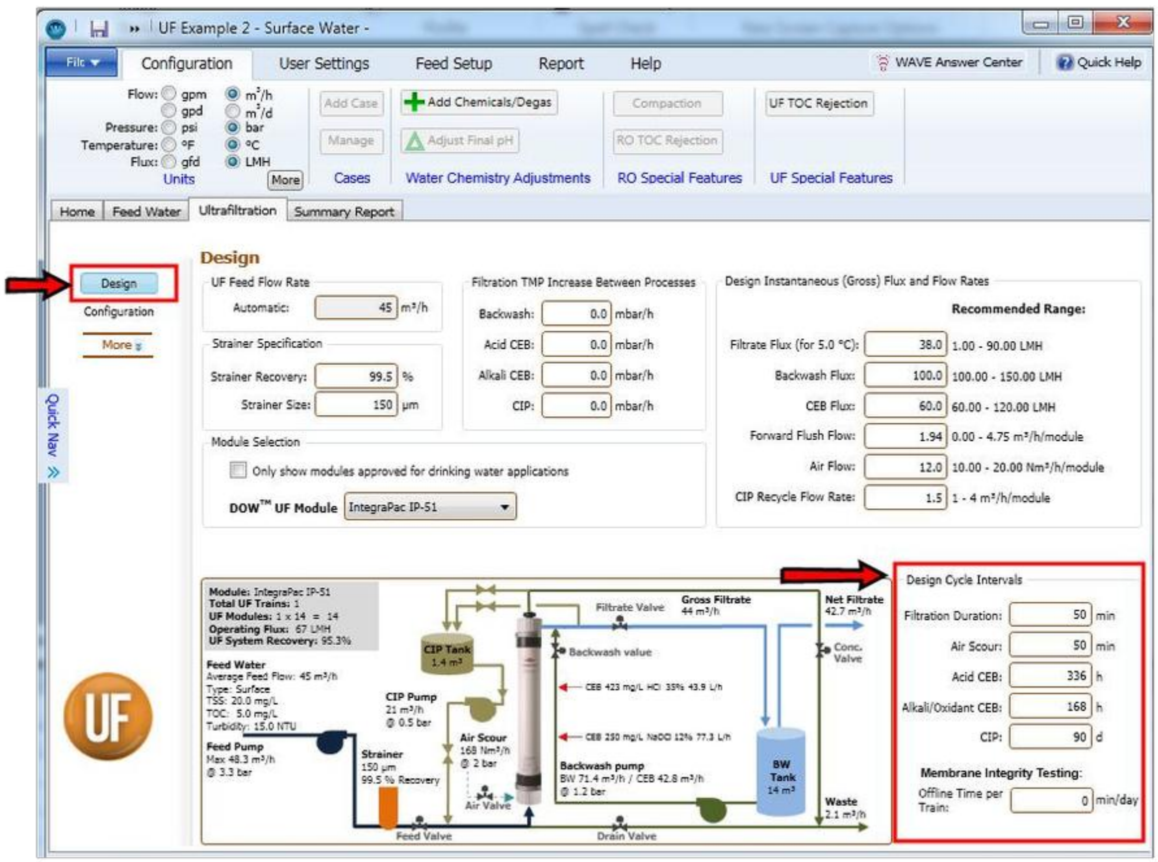


Figure 62. UF Cycle intervals

Note: WAVE populates the cycle intervals by default (based on DUPONT™ Ultrafiltration – General Design Guidelines) and includes limits on the values that can be input by the user.

Membrane Integrity Testing

The integrity of membranes (made into fibers) is periodically tested in most UF systems. While the test itself involves little water (mostly compressed air), the time taken during the test would affect the timing of all the other modes in UF. For that reason it is considered in WAVE. It is possible in WAVE to specify if Membrane Integrity Testing is to be considered and if so, its duration for each train.

Note: By default, WAVE assumes that Membrane Integrity Testing is not considered when looking at the timing of UF modes of operation.

Specifying the Filtration TMP Increase between Processes for UF

WAVE makes possible the specification of increases of pressure drop across the UF membrane (trans membrane pressure or TMP) between successive Backwash, Acid/Alkali CEB and CIP steps per hour.

It will help to estimate the energy needed for ultrafiltration by taking into account solid accumulation/fouling of the UF membrane during use. By using the appropriate rates of TMP increase and Backwash/CEB/CIP frequencies, one can incorporate the effect of deteriorating membrane performance between cleanings.

The TMP increase between processes can be accessed as shown.

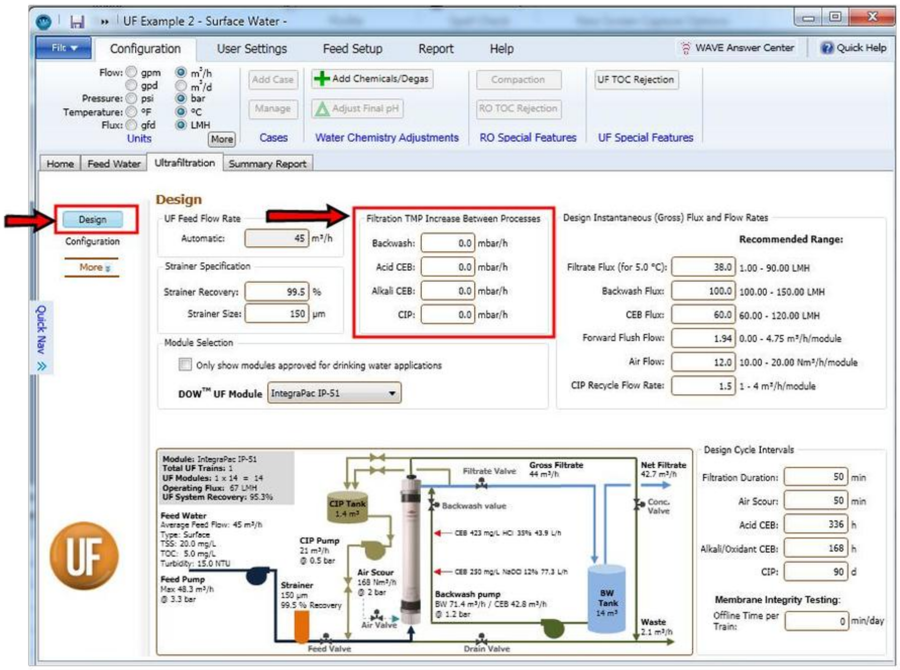


Figure 63. The Filtration Specification Window in WAVE for UF modeling

Notes:

- WAVE sets the values for transmembrane pressure drop (TMP) increase with time to zero by default. The user is urged to use an appropriate value based on data and experience.
- The UF System Diagram is displayed automatically in the Filtration Window and is updated based on the changes made in other Windows.

Specifying the Strainer Size and Recovery

WAVE makes possible the specification of Strainer size and recovery (pretreatment for UF). The Strainer Specification can be accessed as shown.

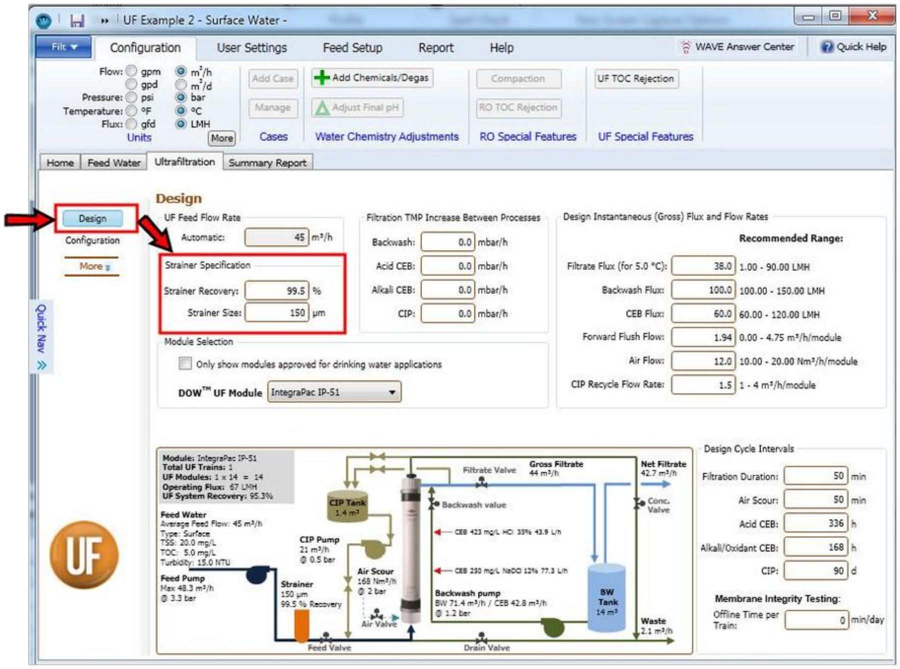


Figure 64. UF Strainer Specification

Note: The Strainer Recovery is set to 99.5% by default in WAVE. A change in the Strainer Recovery would be automatically reflected in the filtrate flowrate. However, the rest of the system design is not directly affected.

3.1.6 Defining the System Configuration

The next window is for definition of the UF Plant Configuration (Figure 65).

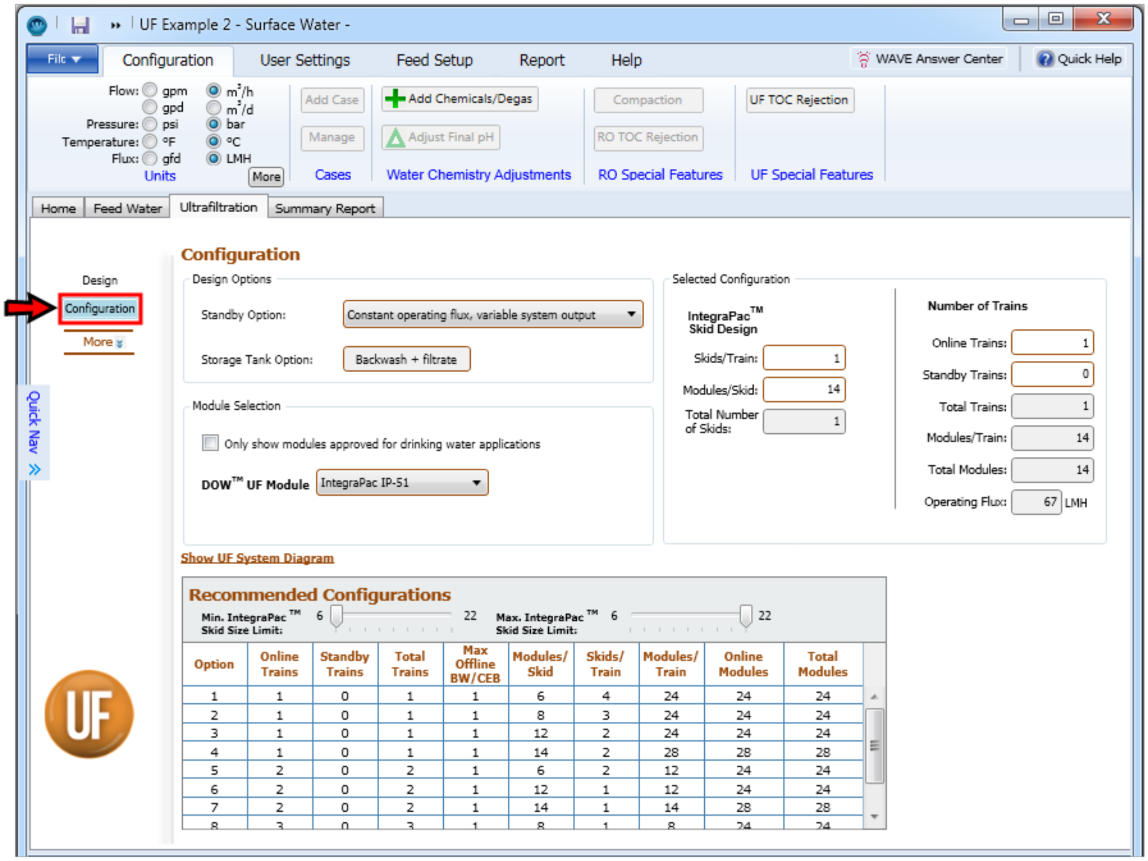


Figure 65. UF Configuration window

Recommended Configurations

The recommended Configurations table is populated based on the flux, cycle duration and module selection (and DUPONT™ Ultrafiltration – General Design Guidelines).

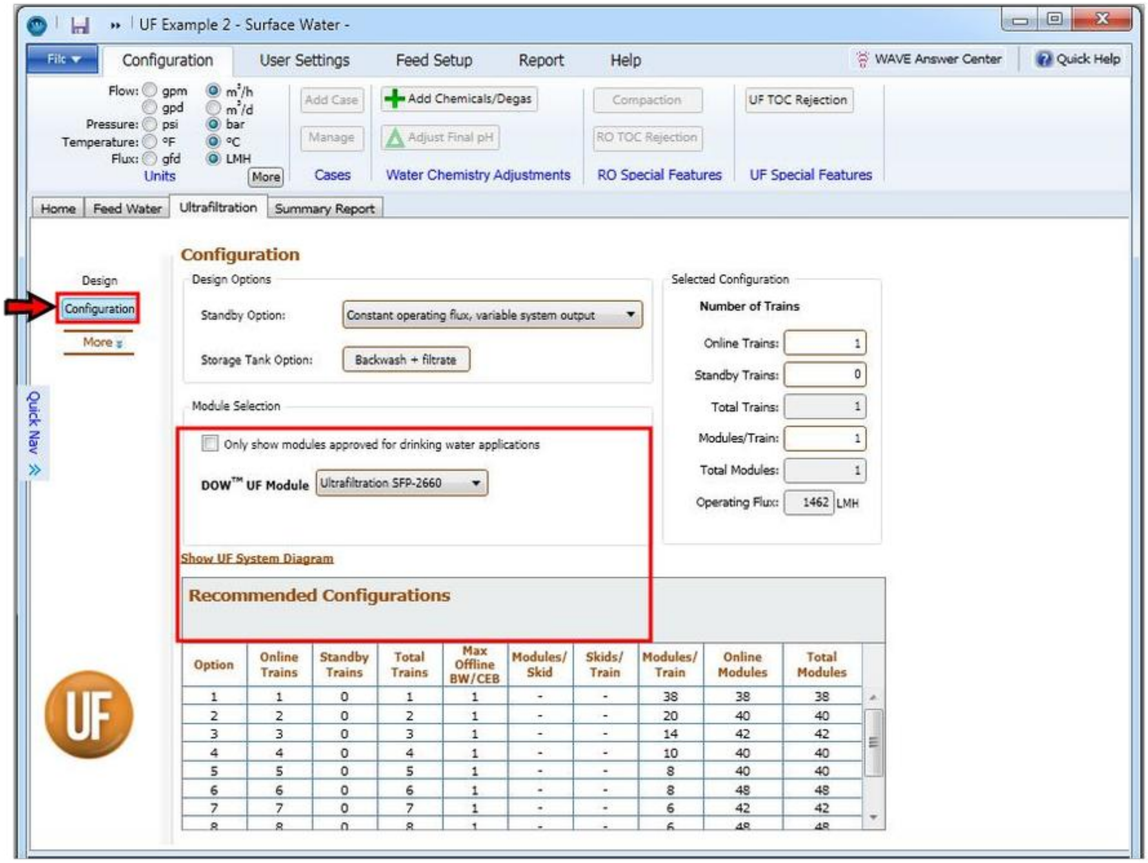


Figure 66. Recommended Configuration Table in UF for non-IntegraPac™

It describes the system design as shown below. Modules/Skid and Skids/Train options can be edited for IntegraPac™ systems.

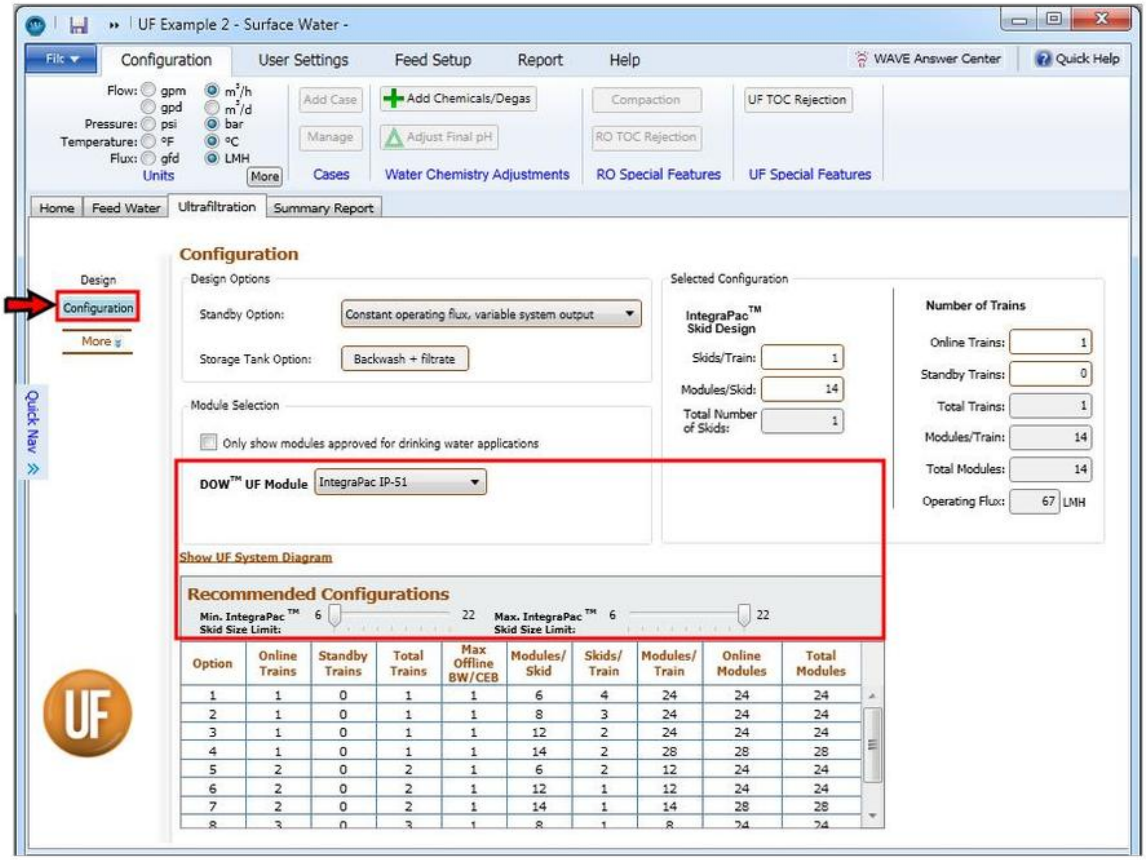


Figure 67. Configuration Table in UF for IntegraPac™

Design options that include the number of Modules/Skid and Skids/Train are supplied by WAVE for IntegraPac™ systems.

Note: By default, WAVE calculated the number of modules per train based on the flux and duration recommendations.

Choosing a Configuration

There are two ways to choose a UF system configuration:

1. Double clicking on one of the rows in the Recommended Configurations Table
2. Directly specifying the number of online trains, BW/CEB standby, CIP standby trains, modules per train, skids per train (IntegraPac™), modules per skid (IntegraPac™) in the respective input fields in the Configuration Window in the Ultrafiltration Tab as shown below.

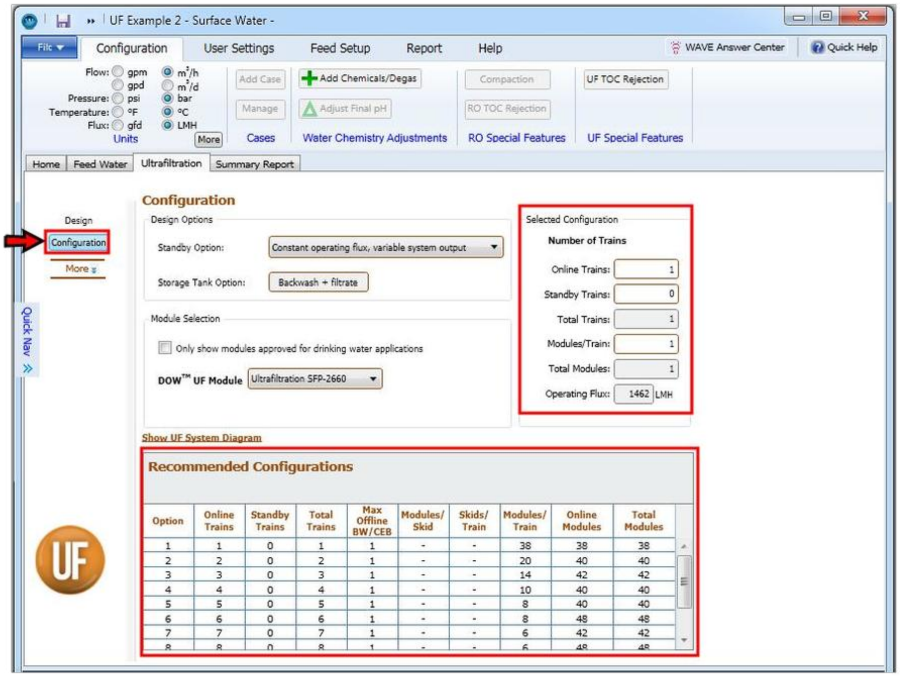


Figure 68. Direct specification of the UF system configuration in the WAVE Configuration Window.

Notes:

- By default, WAVE assumes 1 online train with zero standby trains and 1 module per train to start the computation. For IntegraPac™ systems, WAVE assumes by default 1 skid per train
- The Recommended Configurations Table appears in the Configuration Window. The user can choose a specific configuration by double-clicking on a row in the Table.
- WAVE highlights the selected configuration in the Selected Configuration table in the Configuration Window but it does not highlights the selection in the Recommended Table. The user is urged to check the entries in the Selected Configuration section of the Configuration Window (as shown above) to ensure that the right configuration is specified.

Specifying Other Design Options

In addition to flowrates, fluxes, UF mode durations and system configurations, there are additional design options that can be specified in WAVE (Figure 69 and Figure 70). These options, which affect the size and number of storage tanks, include:

1. Standby Options
2. Storage Tank Options

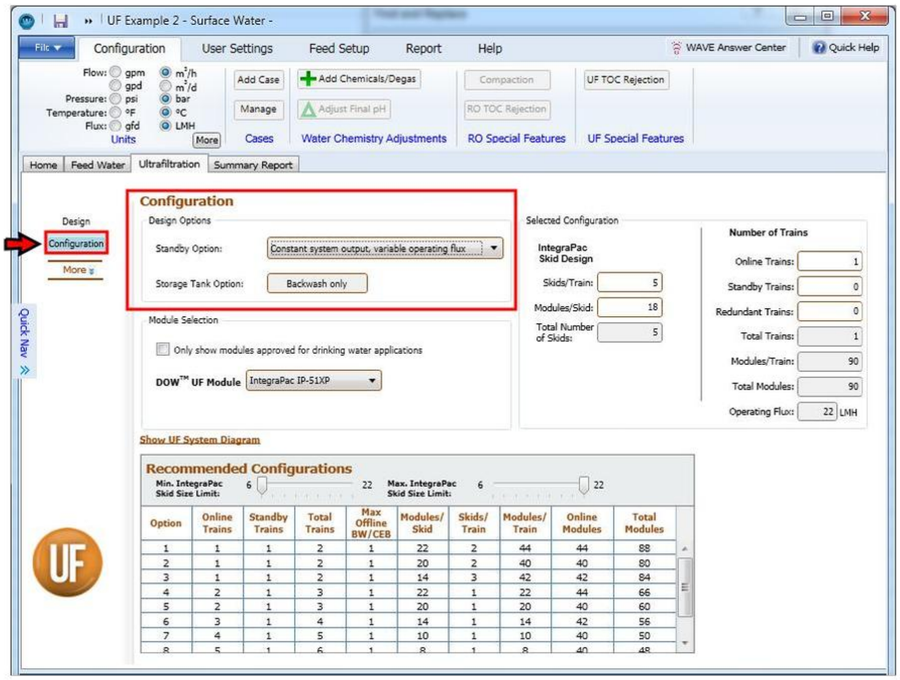


Figure 69. Additional UF system design inputs in WAVE (operating mode)

Standby Options

There are two Standby Options:

1. Constant system output, variable operating flux
2. Constant operating flux, variable system output

Storage Tank Options

WAVE automatically selects Storage Tank Option once the Standby Option is selected. There are two options:

1. BW only: There is no storage tank for the filtrate to ensure constant flow to downstream processes. This might require additional standby modules. Some of the filtrate is siphoned off to be stored for Backwash purposes.
2. BW + filtration: There is a storage tank for the filtrate to ensure constant flow to downstream processes. This might require fewer standby modules. Some of the filtrate is siphoned off to be stored for Backwash purposes.

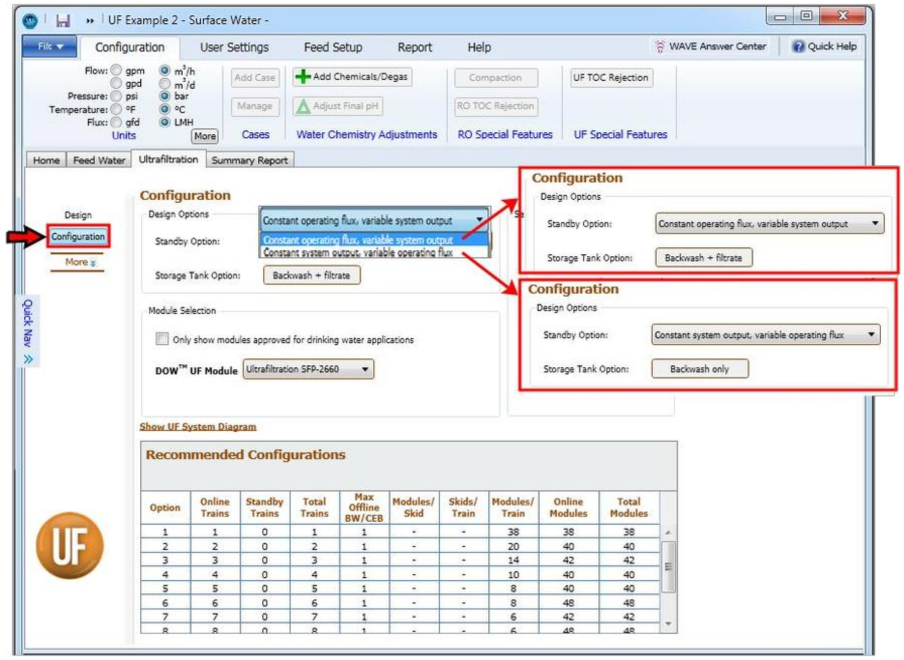


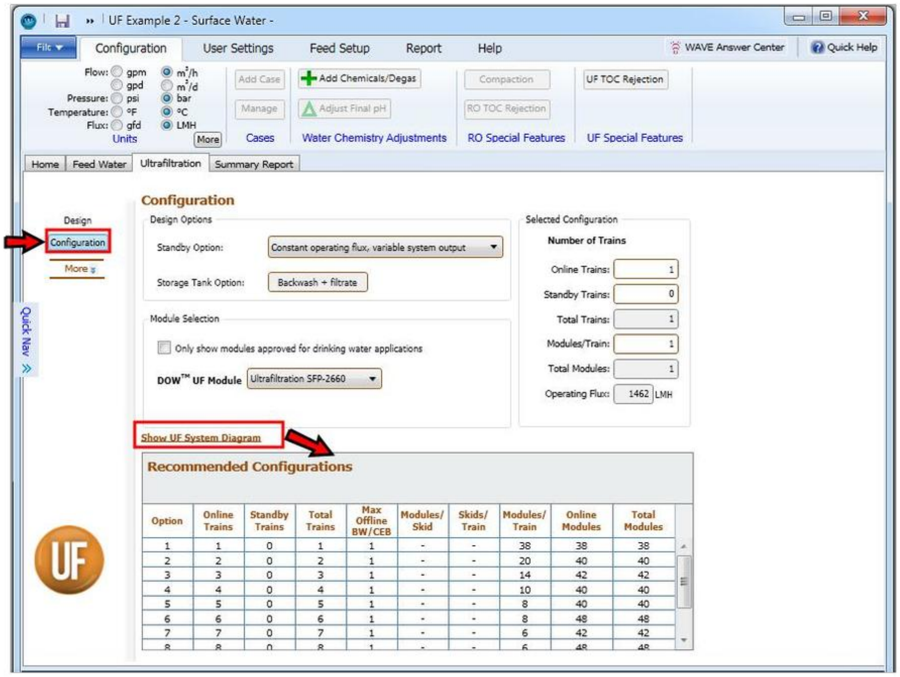
Figure 70. Selection of the Standby option for UF modeling in WAVE

The UF Process Flow Diagram

Based on the information provided in the Design and Configuration Windows, WAVE generated the UF process flow diagram as shown in Figure 71. It is shown interchangeably with the Recommended Configurations Table. One can generate the UF System Diagram by clicking on the "Show UF System Diagram" button as shown in Figure 71. The user can restore the Recommended Configurations Table by clicking on the "Show Recommended Configurations" button as shown in Figure 71.

As shown in in Figure 71, The UF System Diagram displays:

1. Flowrates (feed, product, Backwash, CIP, air scour, chemicals)
2. Feed water composition (TSS, TOC, NTU, SDI)
3. Number of skids and modules
4. UF module type
5. UF system recovery and strainer recovery
6. Tank sizes (Backwash or Backwash + filtrate, CIP)



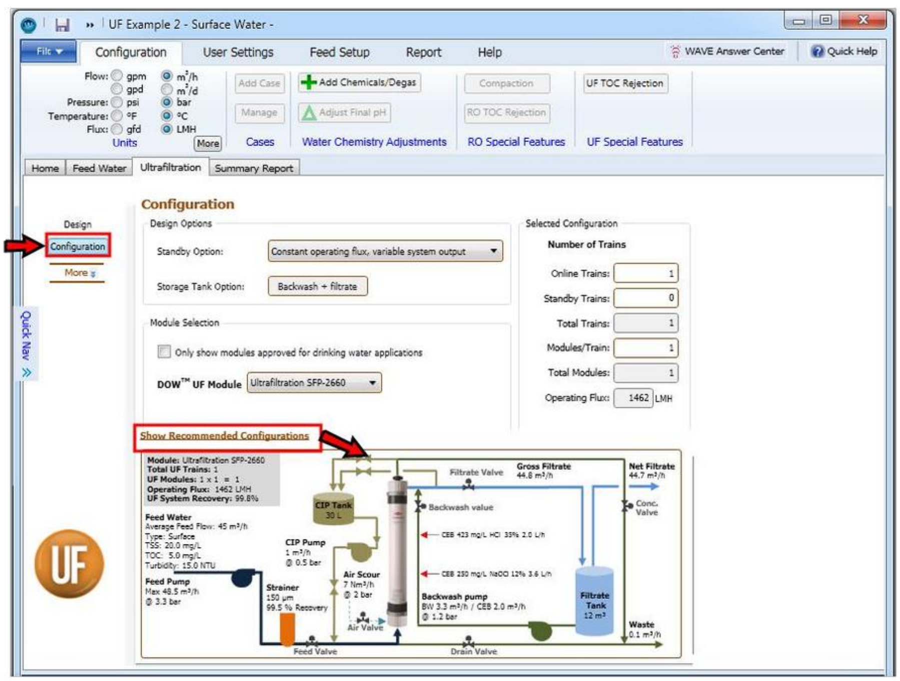


Figure 71. Generating the UF System Diagram restoring the Recommended Configurations Table

Notes:

- Specifications in the Configuration or Design Windows.
- The UF System Diagram can be generated from the Design Window as well as the Configuration Window using the same procedure.
- There would be a CIP Tank even though there may not be a CIP (standby) train.
- When the Backwash (BW), CEB and CIP steps are specified, there would be changes to the UF System Flow Diagram. These are discussed in more detail in upcoming sections.

3.1.7 UF System Operation Details

WAVE can technically model a UF system given only the system configuration information given in the two subsections above (with all other required information supplied by default). However, it is possible to define the different modes of operation of a UF system (Backwash, CEB, CIP) in more detail in WAVE. The windows for specifying the above are revealed for use by clicking on the “More” button as shown in Figure 72. They can be hidden again using the “Less” button as shown in Figure 72.

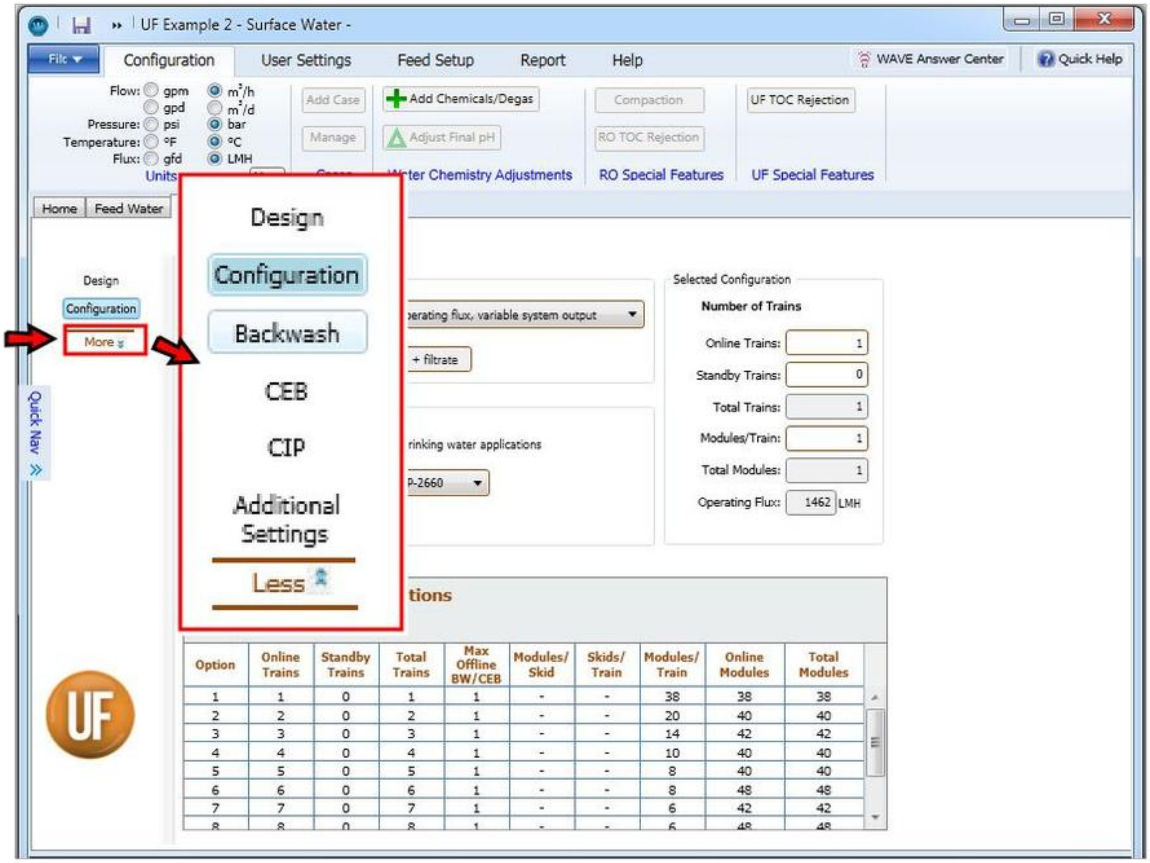


Figure 72. Further options to specify a UF system in WAVE

Specifying the Backwash Mode for UF

Backwash (BW) Mode specification includes the following options:

1. Backwash Temperature
2. Backwash Durations
3. Backwash and Forward Flush Water Sources
4. Oxidant Selection and Dose Specification

Backwash Temperature

WAVE uses the design temperature (specified in the Feed Water Tab) by default (Figure 73).

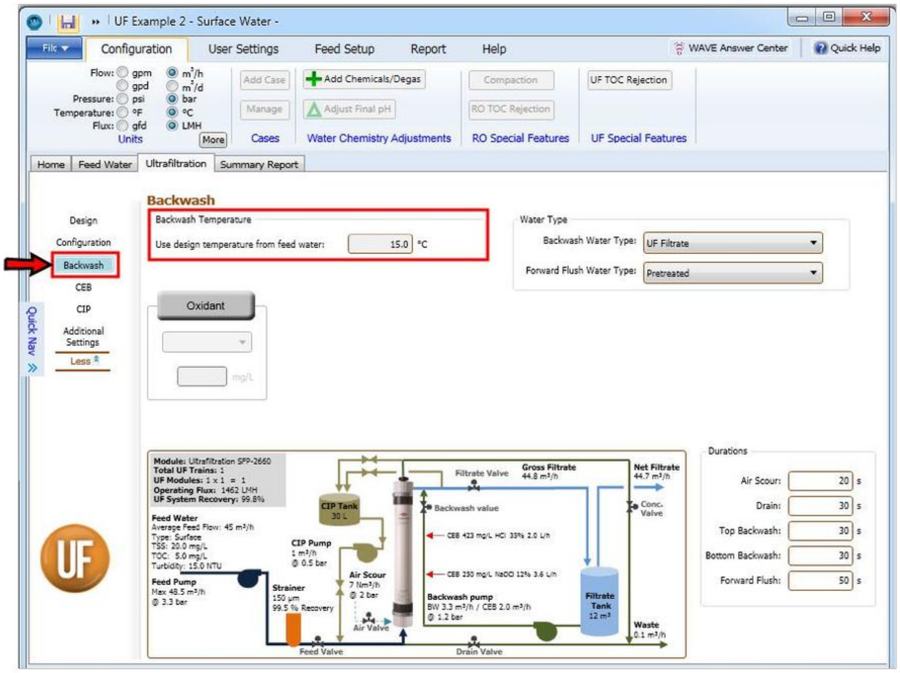


Figure 73. Backwash temperature using the design temperature

Backwash Durations

WAVE populates the durations of the multiple steps within the Backwash mode; Air Scour, Drain, Top and Bottom Backwash, Forward Flush by default based on the feed water type and subtype. However, users can also specify their own duration values as shown in Figure 74.

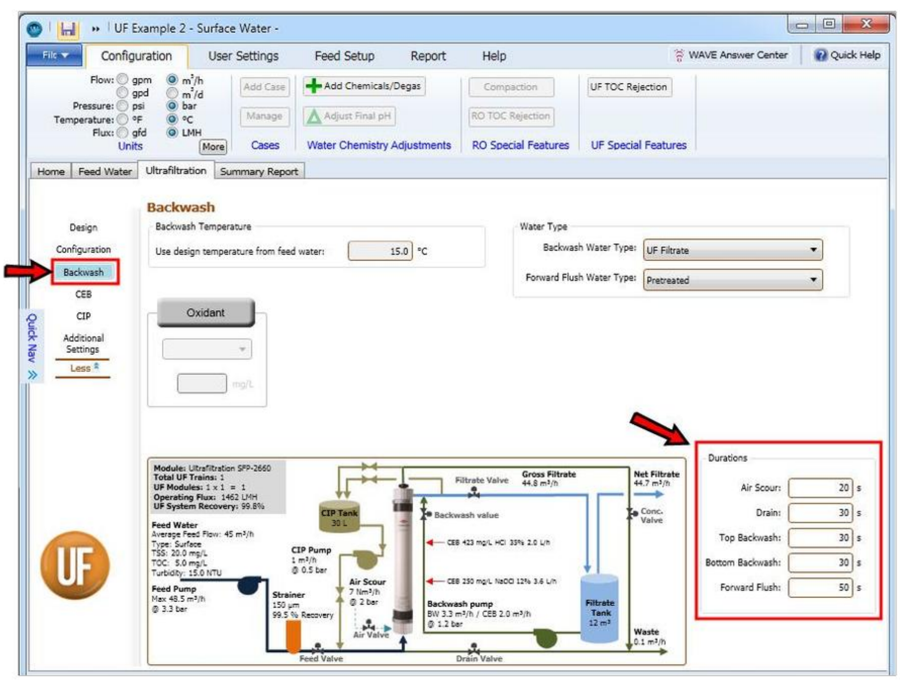


Figure 74. Backwash durations

Notes:

- Currently the effect of different temperatures on the system design (by affecting density/feed pressure) is not included in WAVE.
- Changes to the Top or Bottom Backwash durations would affect the operating flux and would be reflected automatically in the UF System Diagram.
- The WAVE user can specify the Backwash Flux and how far apart the Backwashes are in the Design Window. By modifying the Top and Bottom Backwash durations, the user can effectively modify the amount of water used for Backwash. This would be reflected in the UF system recovery.
- Modifying the Air Scour and Drain durations would affect the Operating Flux, as these would affect the timing of the UF system.
- Modifying the duration of Forward Flush, with flowrate specified in the Design Window and source specified in the Backwash Window, affects the Operating Flux and System Recovery.
- If the user elects to make the CEB durations the same as Backwash durations (as would be discussed in a later section), the effects of changes in Backwash durations, duplicated in CEB durations, would be magnified.

Backwash and Forward Flush Water Sources

A WAVE user can choose between the following options for backwash water source:

- UF filtrate (product of the UF system being designed in WAVE)
- Pretreated water (water that was passed through the Strainer but not the UF modules)

A WAVE user can choose between the same options for Forward Flush water source. The choice can be made as shown in Figure 75.

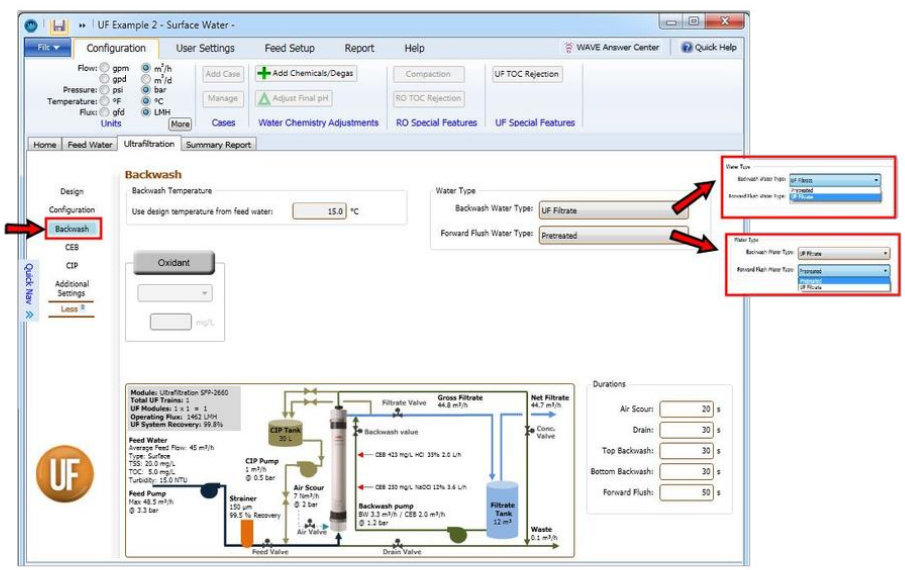


Figure 75. Backwash and Forward Flush water type selection

Note: The effect of choosing different options for Backwash and Forward Flush would be seen after WAVE completes the UF calculations.

Oxidant Selection and Dose Specification

WAVE allows for the addition of an oxidant for more effective cleaning of the UF module during Backwash. This is separate from the use of an oxidant during CEB. An oxidant can be selected and its dose in the Backwash stream specified by following the steps below (Figure 76)

1. Click on the "Oxidant" button to activate it. The grey area would turn green. In addition a line feeding Oxidant to the Backwash line (named BW Oxidant) would appear in the UF System Diagram.
2. Click on the dropdown arrow.
3. Select the oxidant chemical of interest. The name of the chemical and its concentration in BW Oxidant stream would be displayed in the UF System Diagram.
4. Specify the target oxidant concentration in the Backwash stream. The target oxidant concentration in the Backwash stream would appear in the UF System Diagram.
5. Click over or tab to move elsewhere in the Backwash Window.

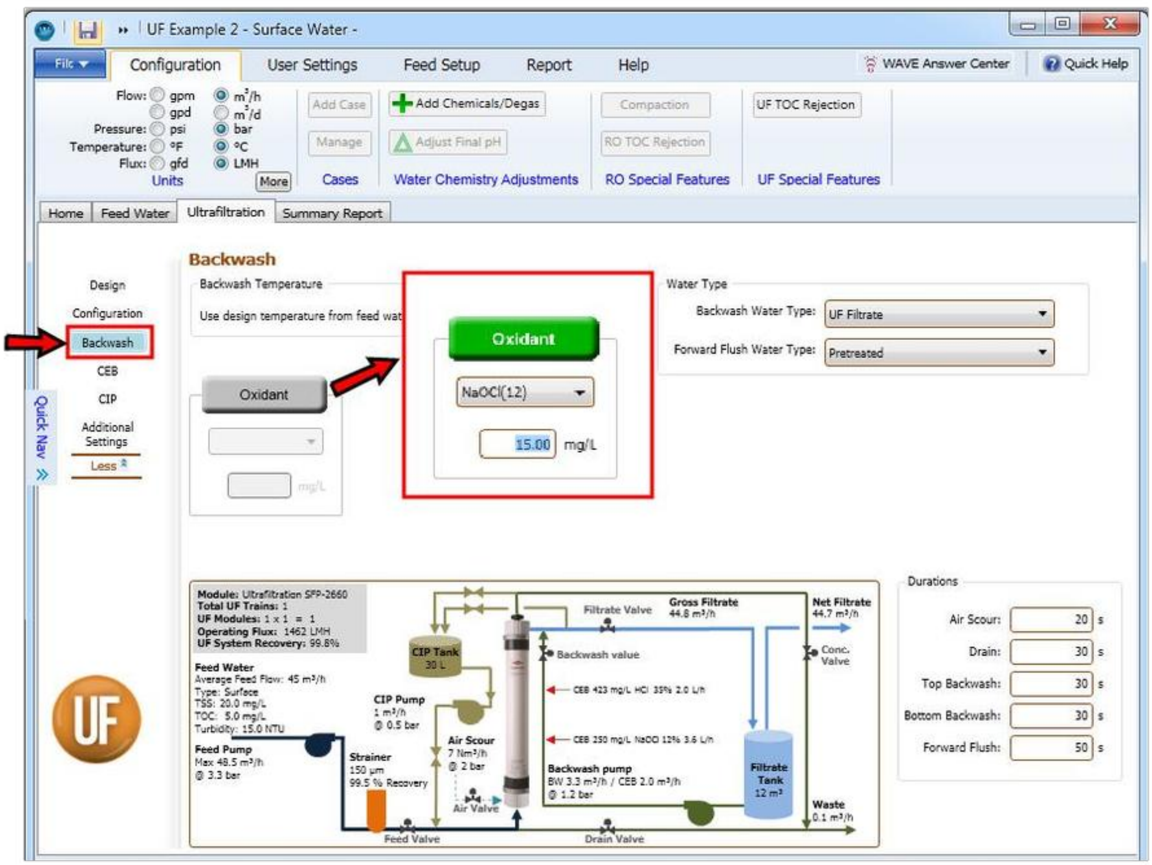


Figure 76. Specification of an oxidant for Backwash (a) Activating the Oxidant option (b) Selecting the Oxidant (c) Specifying the oxidant target concentration in the Backwash stream

Notes:

- The list of oxidants is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- In WAVE, NaOCl would appear as the oxidant chemical by default.
- Clicking on the "Oxidant" button a second time would deactivate the input cell and remove the BW Oxidant line from the UF System Diagram. Setting the target concentration to zero would not remove the BW Oxidant line from the UF System Diagram.

Specifying the Chemically Enhanced Backwash (CEB) Mode for UF

This is similar to the specifying the Backwash Mode.

1. CEB Temperature
2. CEB Durations
3. CEB Mineral Acid Selection and Dose Specification
4. CEB Organic Acid Selection and Dose Specification
5. CEB Alkali Selection and Dose Specification
6. CEB Oxidant Selection and Dose Specification

CEB Temperature

WAVE uses the design temperature (specified in the Feed Water Tab) by default for CEB (Figure 77).

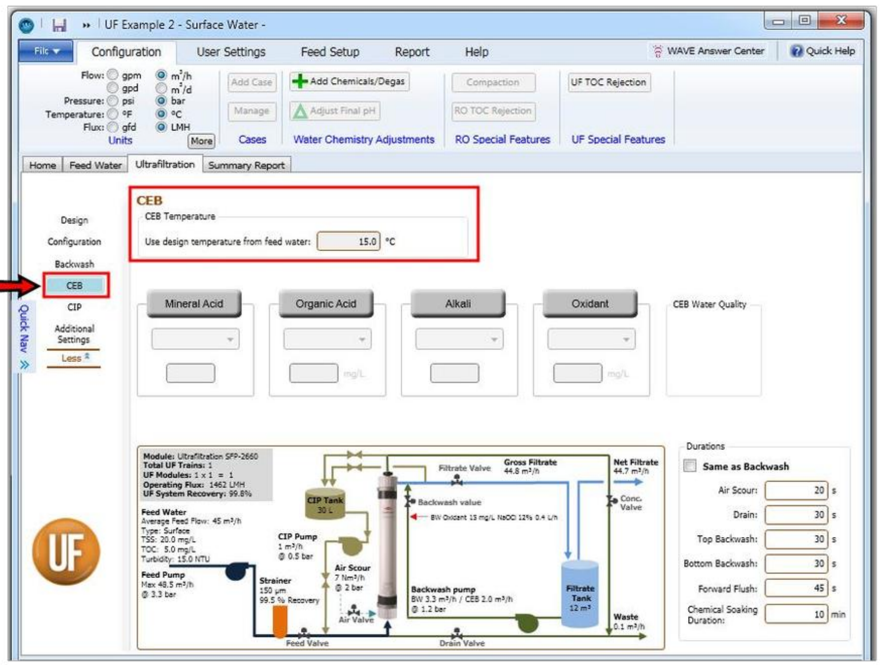


Figure 77. UF CEB specification in WAVE, with default temperature highlighted

Note: Currently the effect of different CEB temperatures on the system design (by affecting density/feed pressure) is not included in WAVE.

CEB Durations

WAVE populates the durations of the multiple steps within the CEB mode; Air Scour, Drain, Top and Bottom Backwash, Forward Flush by default based on the feed water type and subtype. However, users can also specify their own duration values as shown in Figure 78.

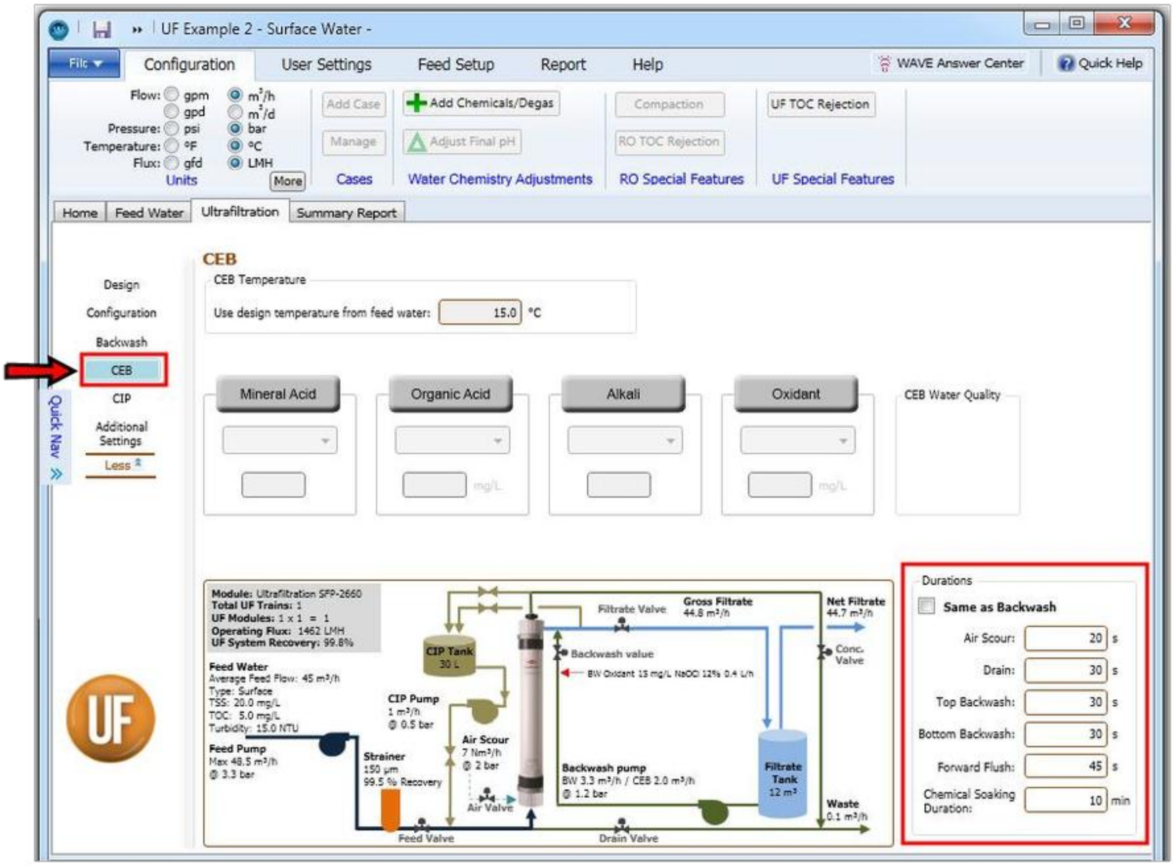


Figure 78. UF CEB durations specification in WAVE

Notes:

- Once the CEB durations are specified to be the same as Backwash durations, any changes in Backwash durations are automatically reflected in CEB durations.
- Changes to the Top or Bottom Backwash durations would affect the operating flux and would be reflected automatically in the UF System Diagram.
- The WAVE user can specify the CEB Flux and how far apart the CEBs are in the Design Window. By modifying the Top and Bottom Backwash durations, the user can effectively modify the amount of water used for Backwash. This would be reflected in the UF system recovery.
- Modifying the Air Scour and Drain durations for CEB would affect the Operating Flux, as these would affect the timing of the UF system.
- Modifying the duration of Forward Flush, with flowrate specified in the Design Window and source specified in the Backwash Window, affects the Operating Flux and System Recovery.

CEB Mineral Acid Selection and Dose Specification

WAVE allows for the addition of a mineral (i.e. inorganic) acid for CEB. This is done by following the steps below (Figure 79):

1. Click on the “Mineral Acid” button to activate it. The grey area would turn green. In addition a line feeding CEB Acid to the Backwash line (named CEB Acid) would appear in the UF System Diagram.
2. Click on the dropdown arrow.
3. Select the mineral acid of interest. The name of the chemical and its concentration in CEB Acid stream would be displayed in the UF System Diagram.
4. Specify the target pH for pH reduction in the CEB stream (if the ionic composition of the feed water is available) or target mineral acid concentration in the CEB stream. The target mineral acid concentration in the CEB stream would appear in the UF System Diagram.
5. Click over or tab to move elsewhere in the CEB Window.

   Specification of a Mineral Acid for CEB (a) Activating the Mineral Acid option (b) Selecting the Mineral Acid (c) Specifying the target pH or concentration in the CEB stream

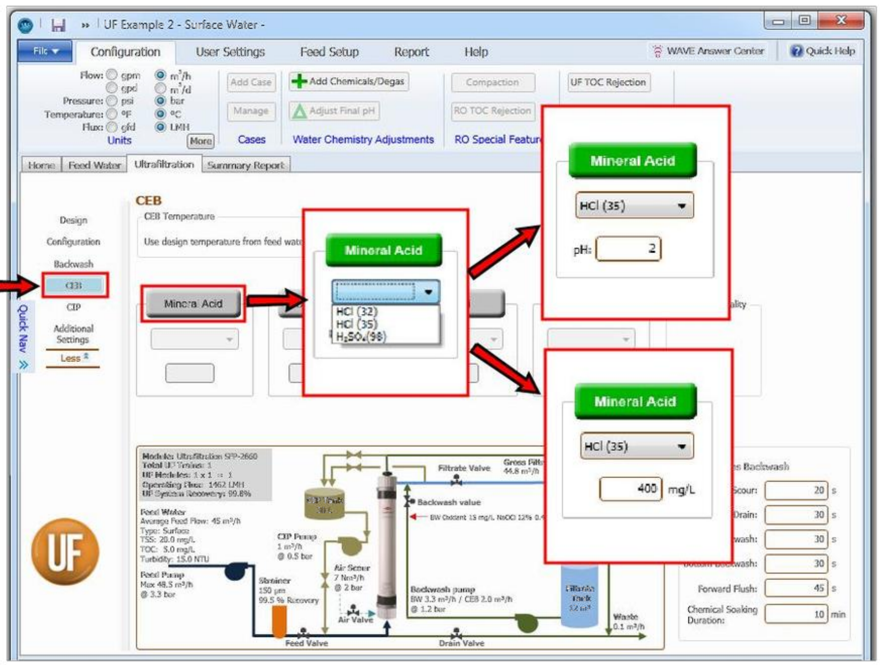


Figure 79. Specification of a Mineral Acid for CEB (a) Activating the Mineral Acid option (b) Selecting the Mineral Acid (c) Specifying the target pH or concentration in the CEB stream

LSI and S&DI Entry during Acid Addition in CEB

If ionic composition is not defined on the feedwater screen, the LSI cell will be blank. Otherwise, if ionic composition is defined, the LSI cell as a pH value is specified (Figure 80). The LSI (Langelier Saturation Index) is an indicator used to determine the need for calcium carbonate scale control. This is important in UF because UF is usually a pretreatment for RO feed. The LSI is applicable for water streams containing up to 10,000 mg/L of total dissolved solids. For water streams containing greater than 10,000 mg/L of total dissolved solids, the Stiff & Davis Stability Index (S&DI) is preferredFigure 82).

Changes in Mineral Acid input in CEB with no Ionic Composition

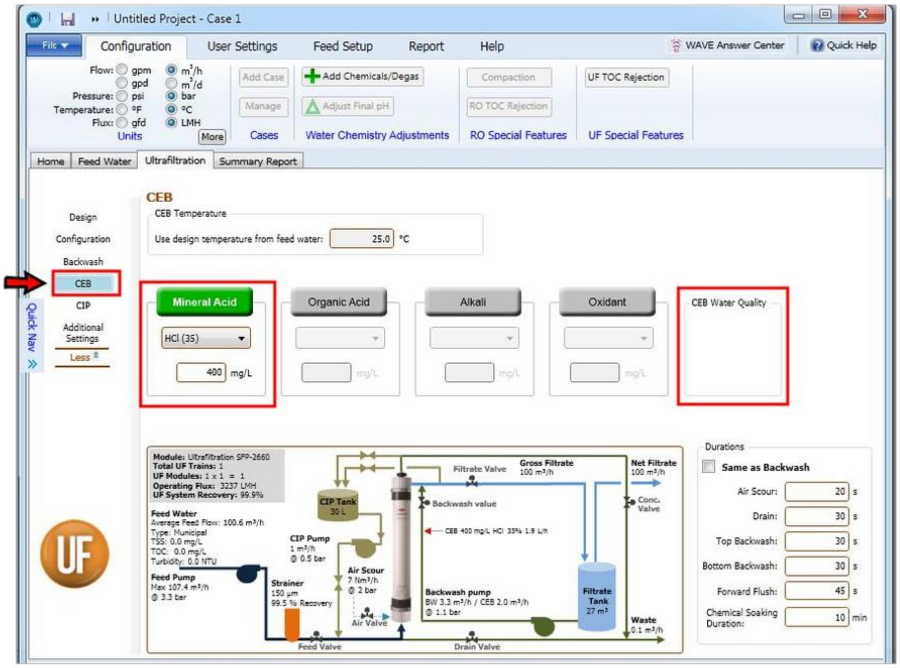


Figure 80. Changes in Mineral Acid input in CEB with no Ionic Composition

Changes in Mineral Acid input in CIP with feed TDS < 10,000 mg/L

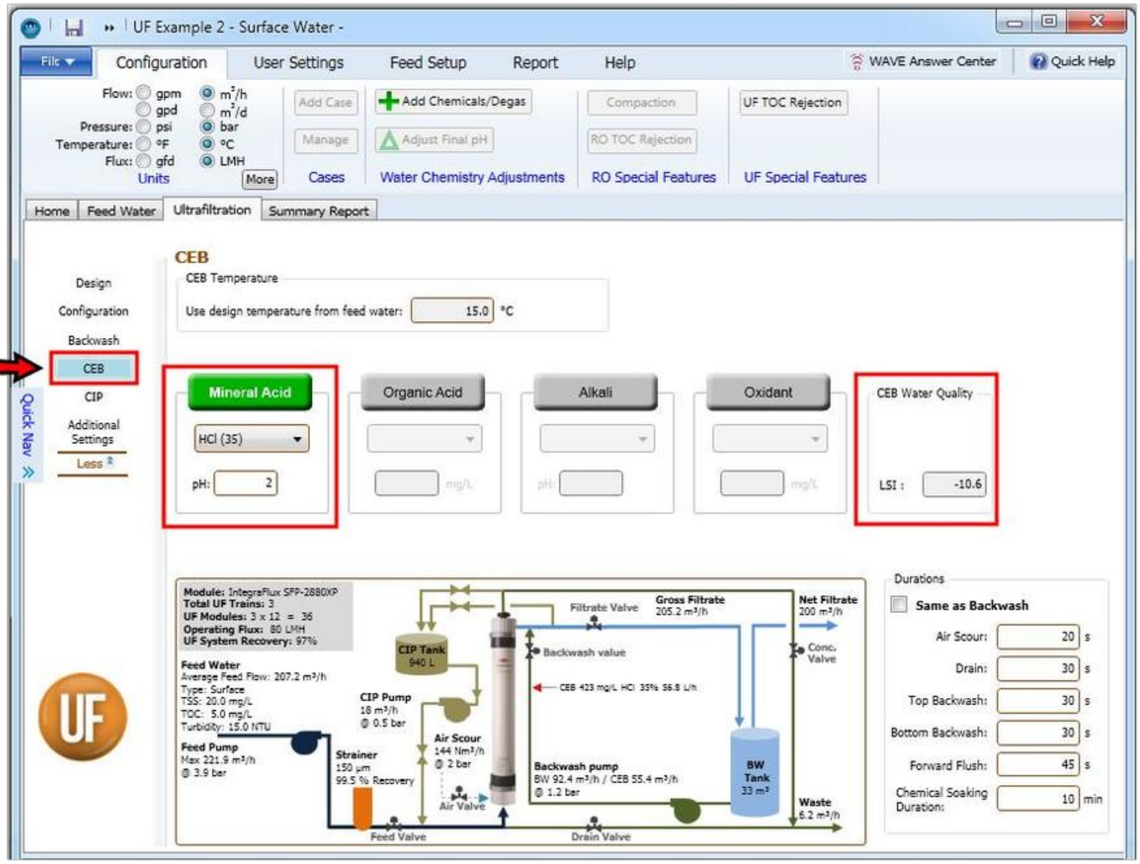


Figure 81. Changes in Mineral Acid input in CIP with feed TDS < 10,000 mg/L

Changes in Mineral Acid input in CIP with feed TDS > 10,000 mg/L

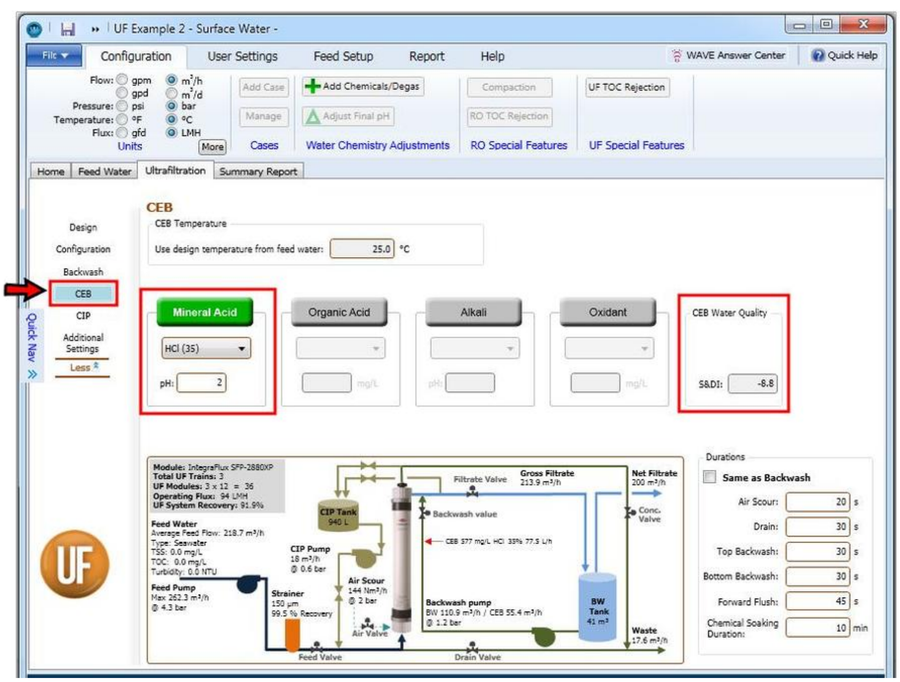


Figure 82. Changes in Mineral Acid input in CIP with feed TDS < 10,000 mg/L

Changes in Alkali input in CIP with feed TDS > 10,000 mg/L

Notes:

- The list of mineral acids is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- The target pH in the CEB stream for pH reduction (if the ionic composition of the feed water is available) or target mineral acid concentration in the CEB stream interconvert automatically, i.e. if the user initially did not have ionic composition data and entered target mineral acid concentration, but later enters some ionic composition data, the target mineral acid concentration is converted to a corresponding pH and vice versa.
- If the "Mineral Acid" button is activated, WAVE would require selection of a mineral acid and a corresponding pH/target concentration.
- Clicking on the "Mineral Acid" button a second time would deactivate the input cell and remove the CEB Acid line from the UF System Diagram. Setting the target concentration to zero would not remove the CEB Acid line from the UF System Diagram.

CEB Organic Acid Selection and Dose Specification

WAVE allows for the addition of an organic acid for CEB. This is done by following the steps below (Figure 83):

1. Click on the "Organic Acid" button to activate it. The grey area would turn green. In addition a line feeding CEB Organic Acid to the Backwash line (named CEB Organic Acid) would appear in the UF System Diagram.
2. Click on the dropdown arrow.
3. Select the organic acid of interest. The name of the chemical and its concentration in CEB Organic Acid stream would be displayed in the UF System Diagram.
4. Specify the target organic acid concentration in the CEB stream. The target mineral acid concentration in the CEB stream would appear in the UF System Diagram.
5. Click over or tab to move elsewhere in the CEB Window.

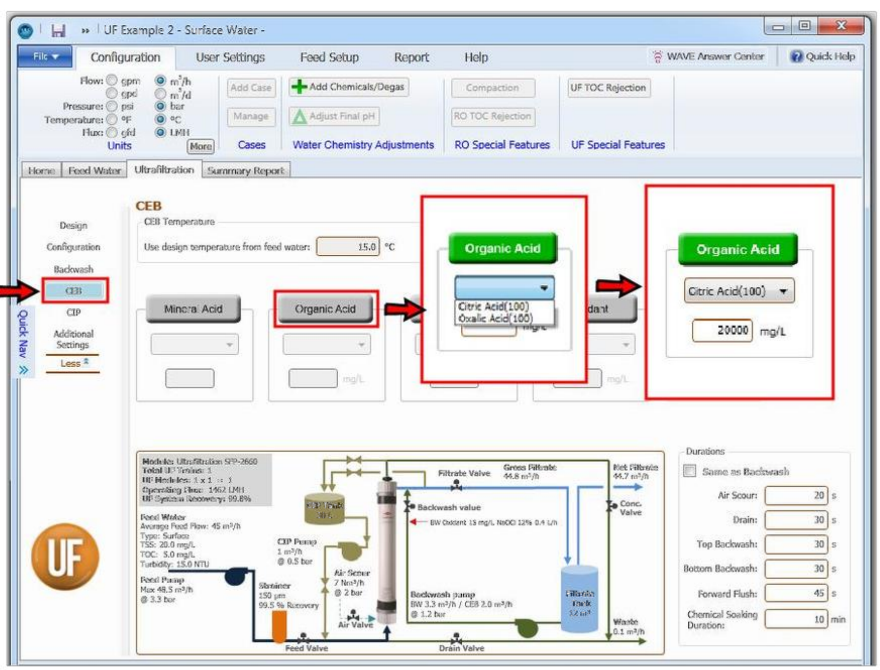


Figure 83. Specification of an Organic Acid for CEB: Activating the Organic Acid option; Selecting the Organic Acid and Specifying the target concentration in the CEB stream

Notes:

- The list of organic acids is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- If the "Organic Acid" button is activated, WAVE would require selection of an organic acid and a corresponding target concentration.
- Clicking on the "Organic Acid" button a second time would deactivate the input cell and remove the CEB Organic Acid line from the UF System Diagram. Setting the target concentration to zero would not remove the CEB Organic Acid line from the UF System Diagram.

CEB Alkali Selection and Dose Specification

WAVE allows for the addition of an alkali for CEB. This is done by following the steps below (Figure 84):

1. Click on the "Alkali" button to activate it. The grey area would turn green. In addition a line feeding CEB Alkali to the Backwash line (named CEB Alkali) would appear in the UF System Diagram.
2. Click on the dropdown arrow.
3. Select the alkali of interest. The name of the chemical and its concentration in CEB Alkali stream would be displayed in the UF System Diagram.
4. Specify the target alkali concentration in the CEB stream. The target alkali concentration in the CEB stream would appear in the UF System Diagram.
5. Click over or tab to move elsewhere in the CEB Window.

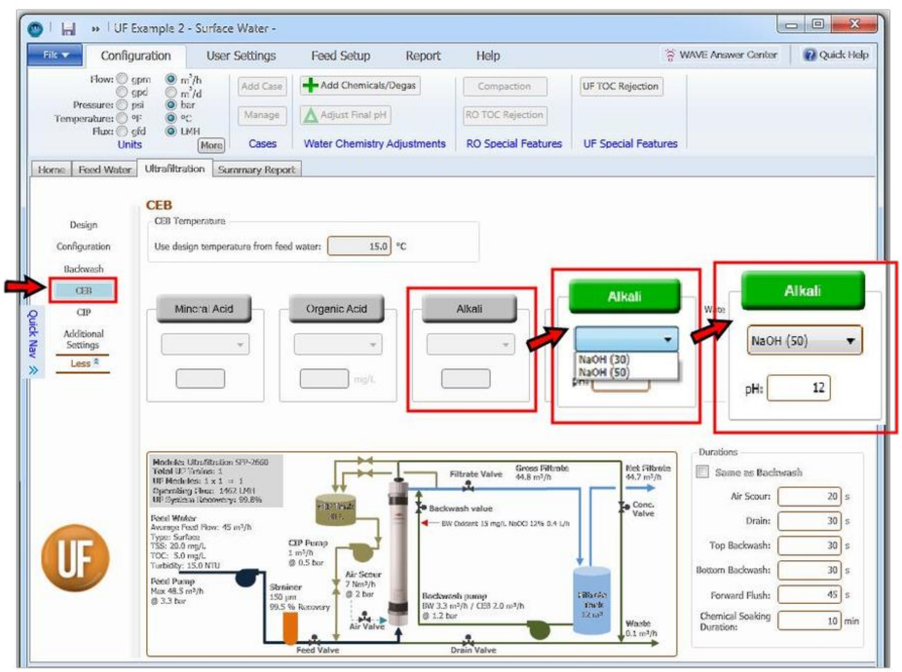


Figure 84. Specification of a Alkali for CEB (a) Activating the Alkali option (b) Selecting the Alkali concentration (c) Specifying the target pH in the CEB stream

LSI and S&DI Entry during Alkali Addition in CEB

One can note the appearance of the LSI cell as a pH value is specified (note the difference between Figure 85 and Figure 86). The LSI is applicable for water streams containing up to 10,000 mg/L of total dissolved solids (Figure 86). For water streams containing greater than 10,000 mg/L of total dissolved solids, the S&DI is preferred (as seen in Figure 88).

CEB Water quality in Alkali input in CEB with feed with no ionic composition

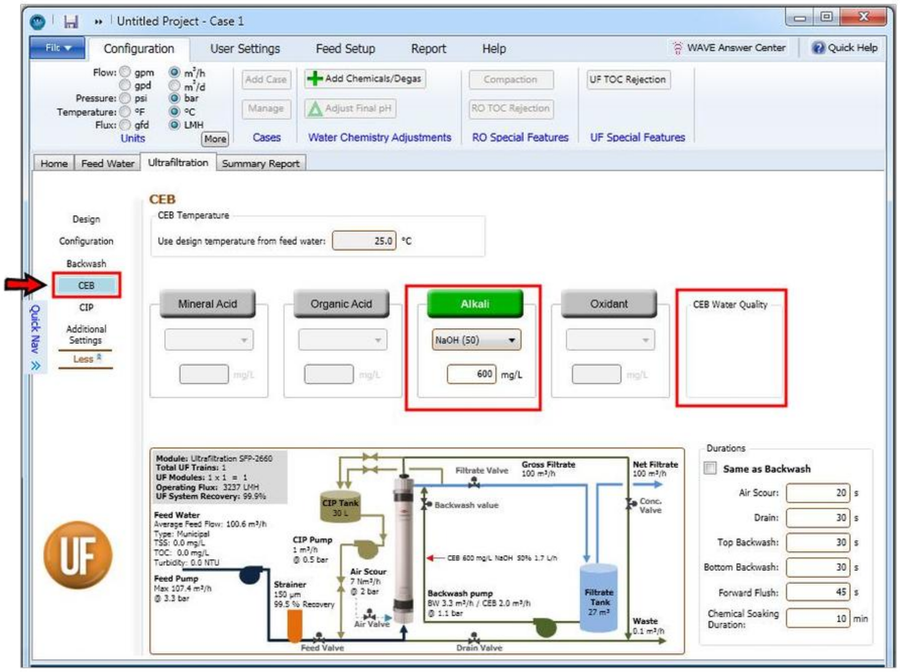


Figure 85. CEB Water quality in Alkali input in CEB with feed with no ionic composition

Changes in Alkali input in CEB with feed TDS < 10.000 mg/L

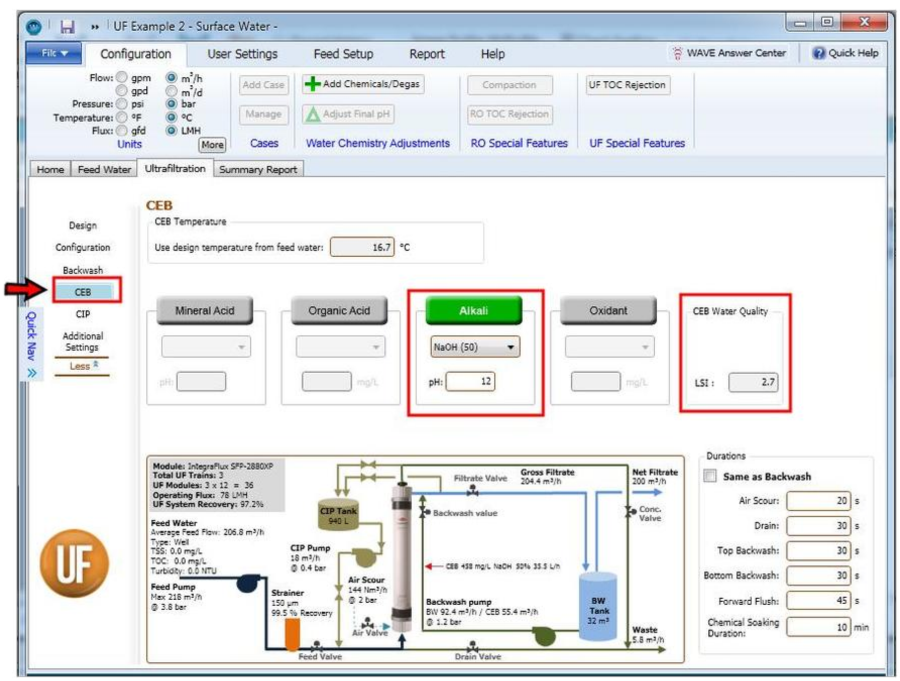


Figure 86. Changes in Alkali input in CEB with feed TDS < 10.000 mg/L

Changes in Alkali input in CIP with feed TDS > 10,000 mg/L

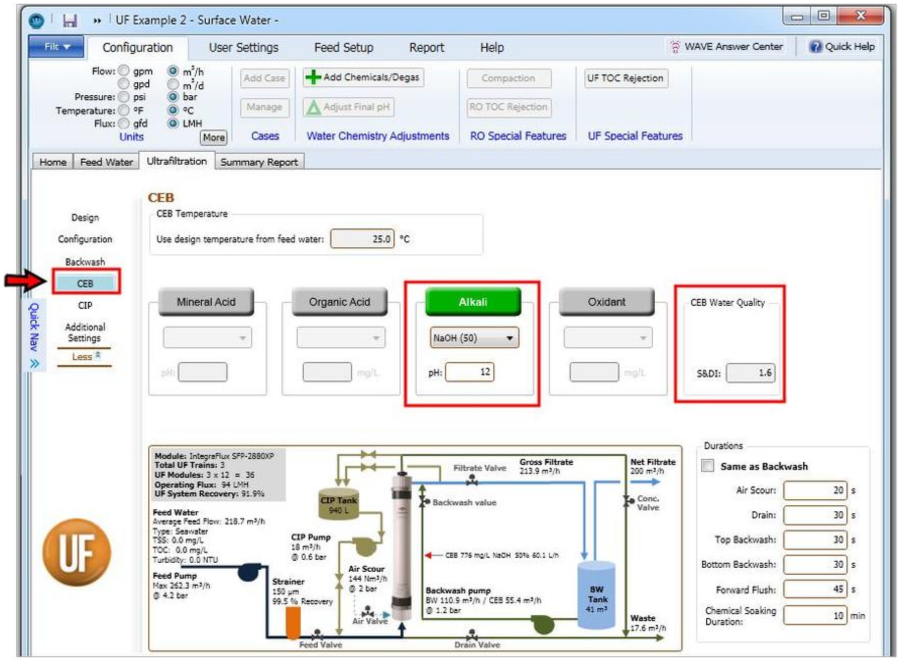


Figure 87. Changes in Alkali input in CIP with feed TDS > 10,000 mg/L

Notes:

- The list of alkali chemicals is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- The target pH in the CEB stream for pH reduction (if the ionic composition of the feed water is available) or target alkali concentration in the CEB stream interconvert automatically, i.e. if the user initially did not have ionic composition data and entered target alkali concentration, but later enters some ionic composition data, the target alkali concentration is converted to a corresponding pH and vice versa.
- If the "Alkali" button is activated, WAVE would require selection of an alkali and a corresponding pH/target concentration.
- Clicking on the "Alkali" button a second time would deactivate the input cell and remove the CEB Alkali from the UF System Diagram. Setting the target concentration to zero would not remove the CEB Alkali line from the UF System Diagram. (c)

CEB Oxidant Selection and Dose Specification

WAVE allows for the addition of an oxidant for CEB. This is done by following the steps below (Figure 88):

1. Click on the "Oxidant" button to activate it. The grey area would turn green. In addition a line feeding CEB oxidant to the Backwash line (named CEB Oxidant) would appear in the UF System Diagram.
2. Click on the dropdown arrow.
3. Select the oxidant of interest. The name of the oxidant chemical and its concentration in the CEB Oxidant stream would be displayed in the UF System Diagram.
4. Specify the target oxidant concentration in the CEB stream. The target oxidant concentration in the CEB stream would appear in the UF System Diagram.
5. Click over or tab to move elsewhere in the CEB Window.

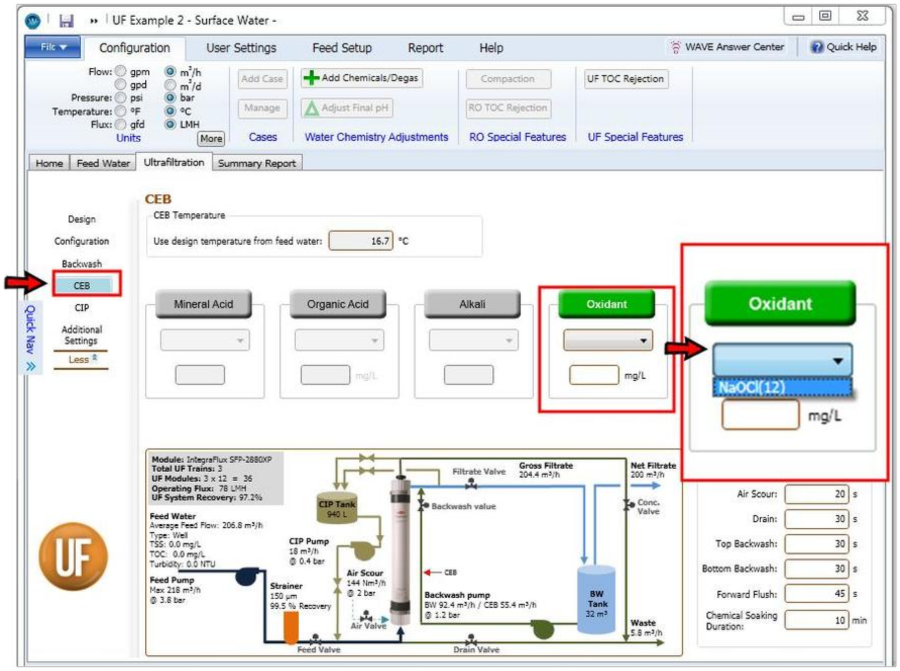


Figure 88. Specification of an Oxidant for CEB (a) Activating the Oxidant option (b) Selecting the Oxidant (c) Specifying the target pH or concentration in the CEB stream

Notes:

- The list of Oxidants is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- If the "Oxidant" button is activated, WAVE would require selection of an oxidant and a corresponding target concentration.
- Clicking on the "Oxidant" button a second time would deactivate the input cell and remove the CEB Oxidant line from the UF System Diagram. Setting the target concentration to zero would not remove the CEB Oxidant line from the UF System Diagram.

Specifying the Clean-In-Place (CIP) Mode for UF

This is similar to the specifying the Backwash and CEB Modes.

1. Number of Backwash (BW) steps within a CIP
2. CIP Source Water
3. CIP Recycle Flowrate
4. CIP Temperature
5. CIP Durations
6. CIP Mineral Acid Selection and Dose Specification
7. CIP Organic Acid Selection and Dose Specification
8. CIP Alkali Selection and Dose Specification
9. CIP Oxidant Selection and Dose Specification

Number of Backwash (BW) steps within a CIP

The most thorough cleaning for a UF module requires the clean in place (CIP) process. The unit operations of a CIP involve:

1. An initial Backwash sequence
2. Soak and Backwash for each chemical used
3. The number of Backwashes for the CIP can be specified as shown in .

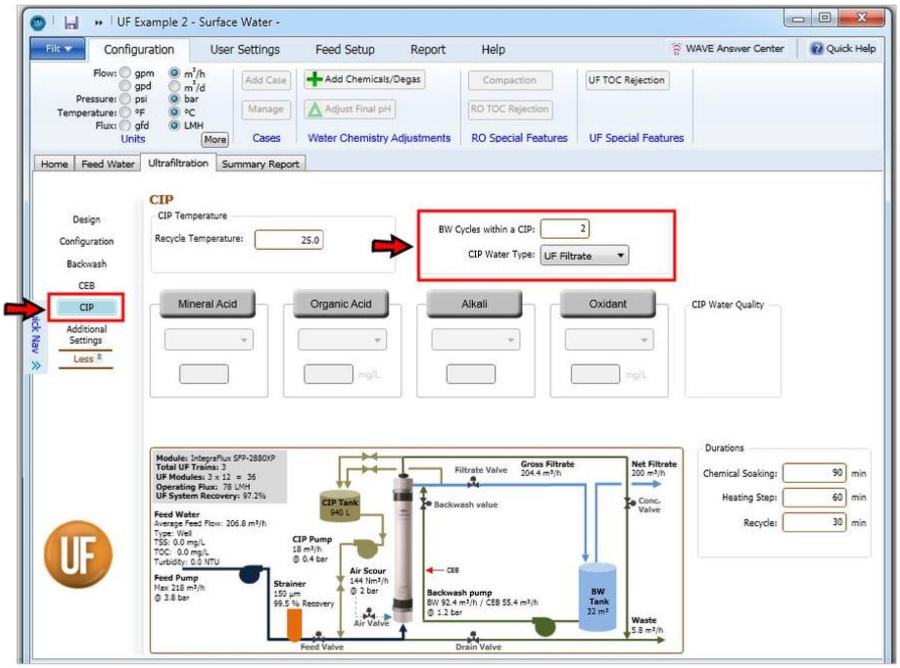


Figure 89. The CIP specification window for UF modeling in WAVE

Note: By default, WAVE includes 2 backwashes within a CIP

CIP Source Water

A WAVE user can choose between the following options for CIP water source:

- UF filtrate (product of the UF system being designed in WAVE)
- Pretreated water (water that was passed through the Strainer but not the UF modules)

The choice can be made as shown in Figure 90.

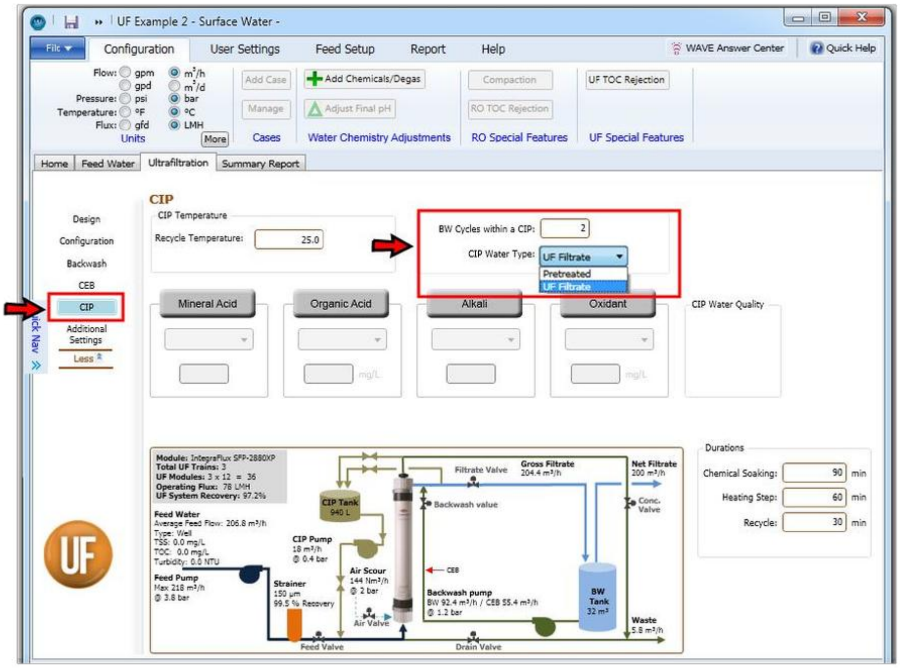


Figure 90. The CIP Water Type specification window for UF modeling in WAVE

Notes:

- The effect of choosing different options for Backwash and Forward Flush would be seen after WAVE completes the UF calculations.
- The default source water for CIP is UF Filtrate.

CIP Recycle Flowrate

CIP chemicals are circulated (recycled) through the UF fibers and housing to clean the system. This flowrate can be specified in the ¨Design¨ window as shown in Figure 92. From the recycle flow rate and duration, the user can calculate the volume of CIP chemicals needed per module.

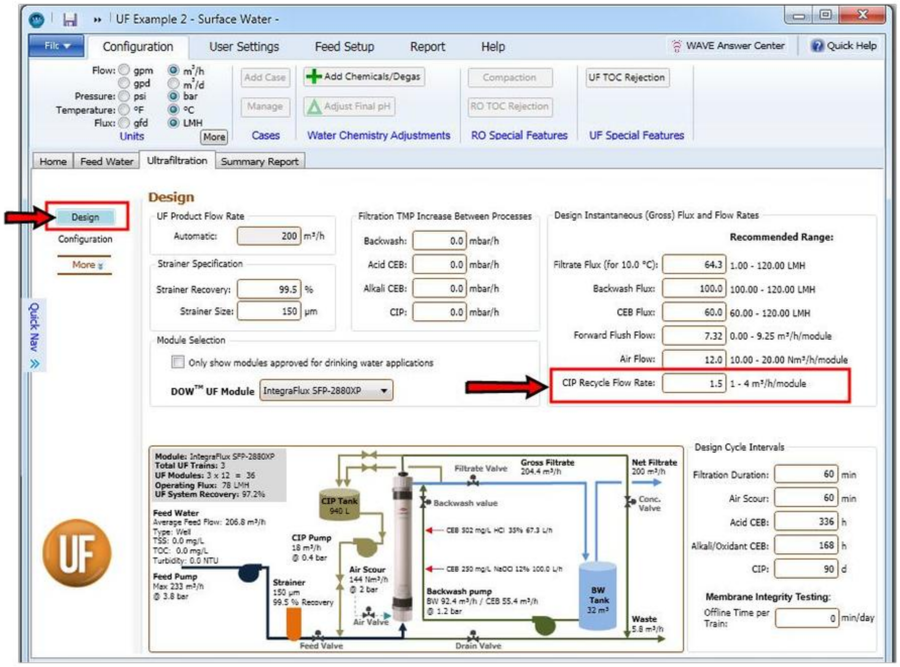


Figure 91. The CIP Recycle Flow Rate modification

Notes:

- 2 m3/h/module is used as the default CIP recycle flowrate in WAVE. It is limited between 1 and 4.
- The effect of changing the CIP recycle flowrate is seen after WAVE models the UF system.

CIP Temperature

The CIP solution can be heated to improve its effectiveness at removing contaminants from the UF membrane. It has the same limits as CEB temperature (1-40°C). It can be specified as shown in Figure 92.

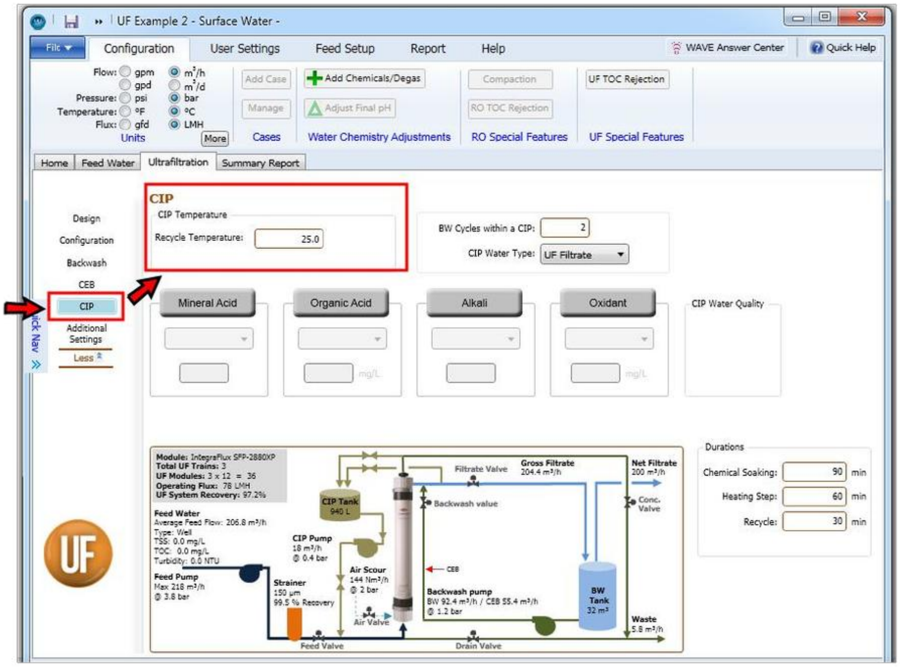


Figure 92. The CIP temperature specification window for UF modeling in WAVE

Note: Currently the effect of different CIP temperatures on the system design (by affecting density/feed pressure) is not included in WAVE.

CIP Durations

Three durations can be defined for CIP in WAVE (as shown in Figure 93):

1. Chemical Soaking duration – the amount of time the UF module is soaked in each chemical during CIP
2. Heating Step duration – the amount of time taken daily to heat the CIP chemicals from the UF system design temperature up to the CIP temperature (to calculate energy consumption)
3. CIP Recycle duration – the amount of time during which the CIP solution is circulated through the UF module

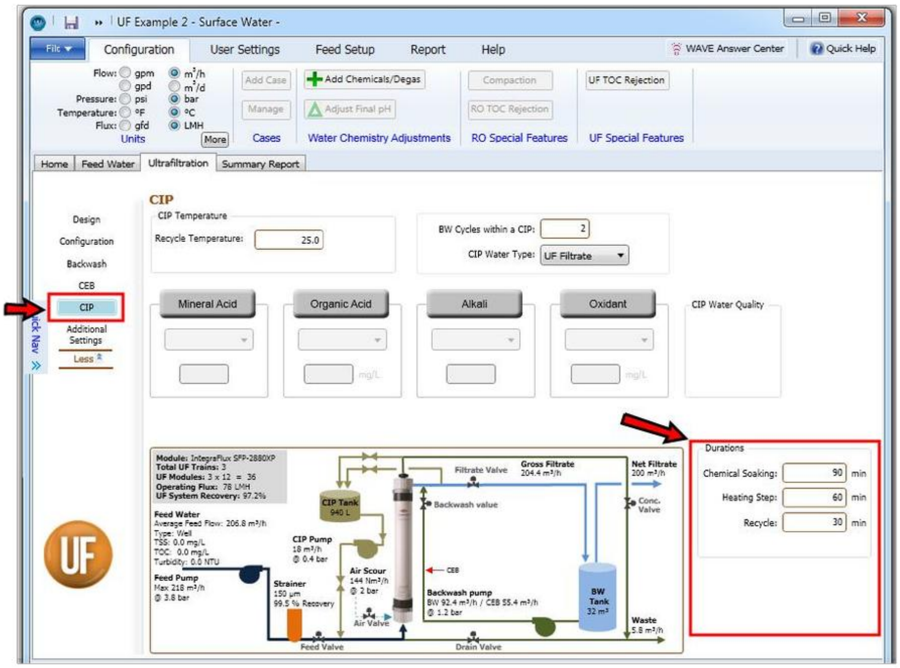


Figure 93. The CIP duration specification window for UF modeling in WAVE

Note: Additional energy will be required to maintain the CIP temperature; however, that is outside the scope of WAVE.

CIP Mineral Acid Selection and Dose Specification

WAVE allows for the addition of a mineral (i.e. inorganic) acid for CIP. This is done by following the steps below (Figure 94):

1. Click on the "Mineral Acid" button to activate it. The grey area would turn green.
2. Click on the dropdown arrow.
3. Select the mineral acid of interest.
4. Specify the target pH for pH reduction for CIP (if the ionic composition of the feed water is available) or target mineral acid concentration in the CIP stream.
5. Click over or tab to move elsewhere in the CIP Window.

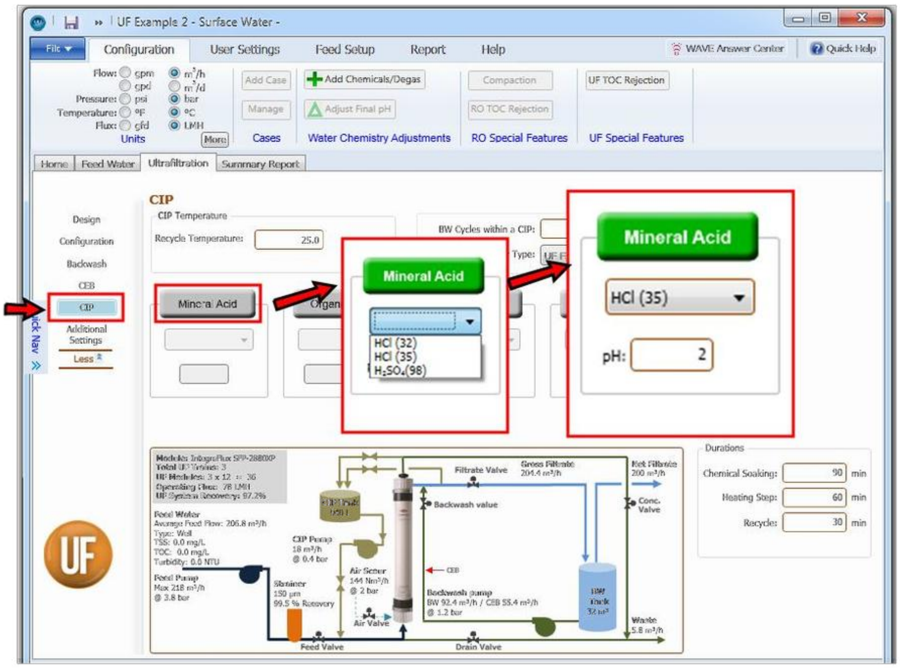


Figure 94. Specification of a Mineral Acid for CIP (a) Activating the Mineral Acid option (b) Selecting the Mineral Acid (c) Specifying the target pH in the CIP stream

LSI and S&DI Entry during Mineral Acid Addition in CIP

The LSI value cell appears as a pH value is specified (note the difference between Figure 95 and Figure 96). The LSI (Langelier Saturation Index) is an indicator used to determine the need for calcium carbonate scale control. The LSI is applicable for water streams containing up to 10,000 mg/L of total dissolved solids (TDS). For water streams containing more than 10,000 mg/L of TDS, the Stiff & Davis Stability Index (S&DI) is preferred (as seen in Figure 97).

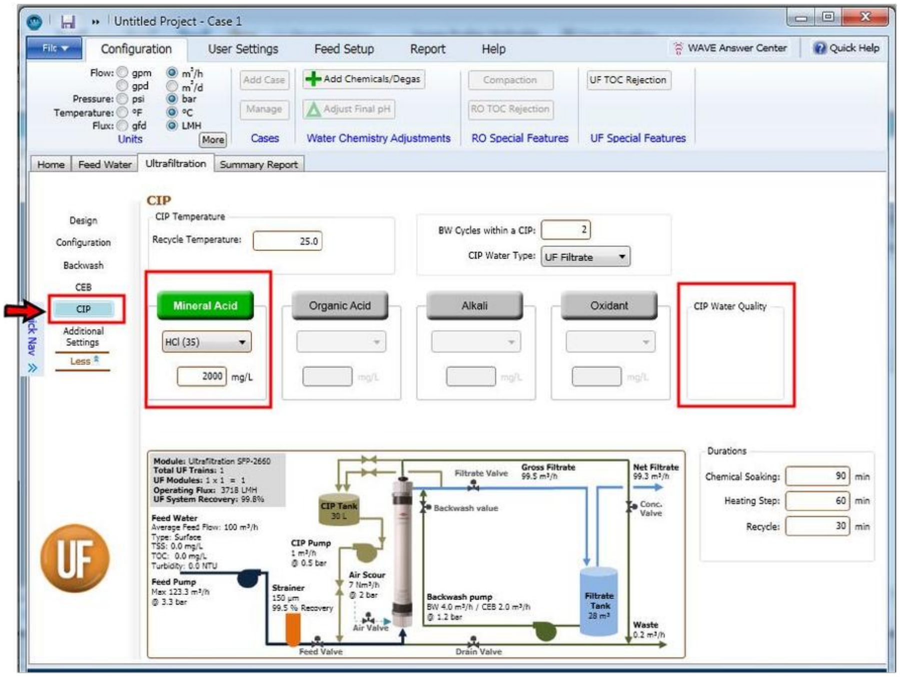


Figure 95. CIP Water quality in Mineral Acid input in CIP with feed with no ionic composition

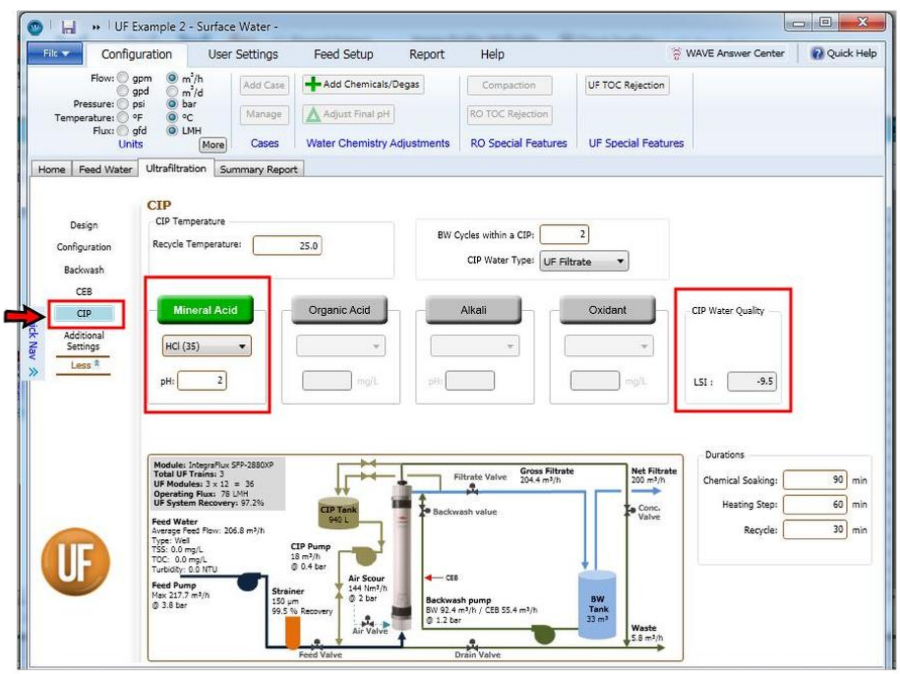


Figure 96. Changes in Mineral Acid input in CIP with feed TDS < 10,000 mg/L

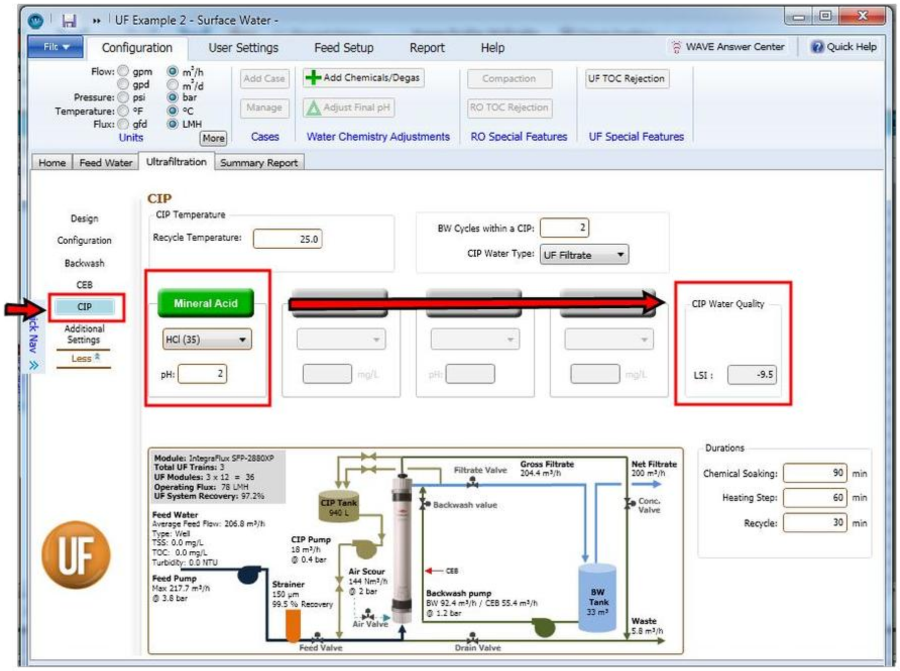


Figure 97. Changes in Mineral Acid input in CIP with feed TDS > 10,000 mg/L

Notes:

- The list of mineral acids is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- The target pH in the CIP stream for pH reduction (if the ionic composition of the feed water is available) or target mineral acid concentration in the CIP stream interconvert automatically, i.e. if the user initially did not have ionic composition data and entered target mineral acid concentration, but later enters some ionic composition data, the target mineral acid concentration is converted to a corresponding pH and vice versa.
- If the "Mineral Acid" button is activated, WAVE would require selection of a mineral acid and a corresponding pH/target concentration.
- Clicking on the "Mineral Acid" button a second time would deactivate the input cell.

CIP Organic Acid Selection and Dose Specification

WAVE allows for the addition of an organic acid for CIP. This is done by following the steps below (Figure 98):

1. Click on the "Organic Acid" button to activate it. The grey area would turn green.
2. Click on the dropdown arrow.
3. Select the organic acid of interest.
4. Specify the target organic acid concentration in the CIP stream.
5. Click over or tab to move elsewhere in the CIP Window.

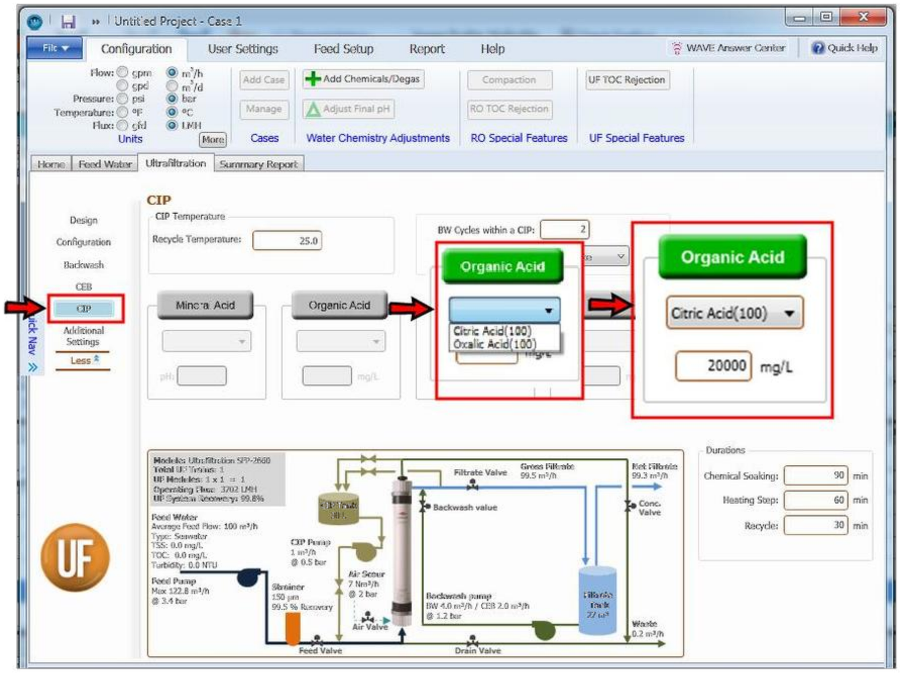


Figure 98. Specification of an Organic Acid for CIP (a) Activating the Organic Acid option (b) Selecting the Organic Acid (c) Specifying the target concentration in the CIP stream

CIP Alkali Selection and Dose Specification

WAVE allows for the addition of an alkali for CIP. This is done by following the steps below (Figure 99):

1. Click on the "Alkali" button to activate it. The grey area would turn green
2. Click on the dropdown arrow.
3. Select the alkali of interest.
4. Specify the target alkali concentration in the CIP stream.
5. Click over or tab to move elsewhere in the CIP Window.

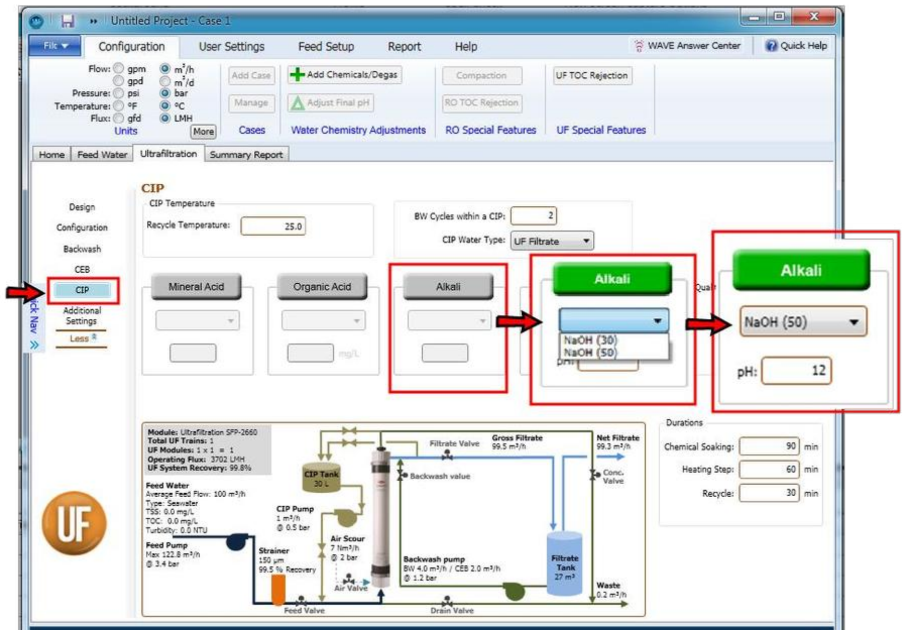


Figure 99. Specification of Alkali for CIP (a) Activating the Alkali option (b) Selecting the Alkali (c) Specifying the target pH in the CIP stream

LSI and S&DI Entry during Alkali Addition in CIP

One can note the appearance of the LSI cell as a pH value is specified (Figure 100 and Figure 101). The LSI is applicable for water streams containing up to 10,000 mg/L of total dissolved solids (Figure 102). For water streams containing greater than 10,000 mg/L of total dissolved solids, the S&DI is preferred (as seen in Figure 102).

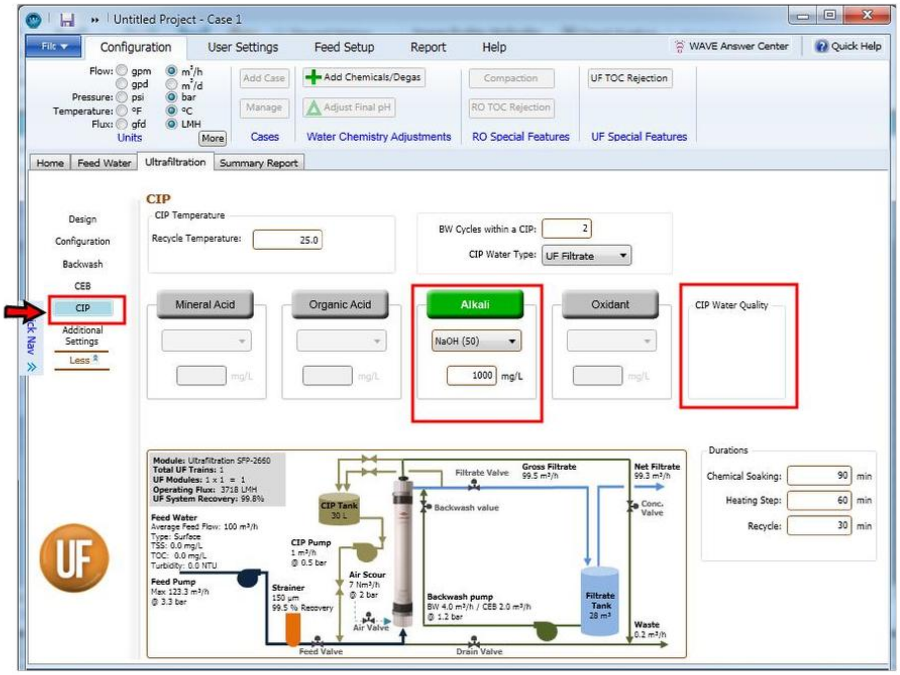


Figure 100. CIP Water quality in Alkali input in CIP with feed with no ionic composition

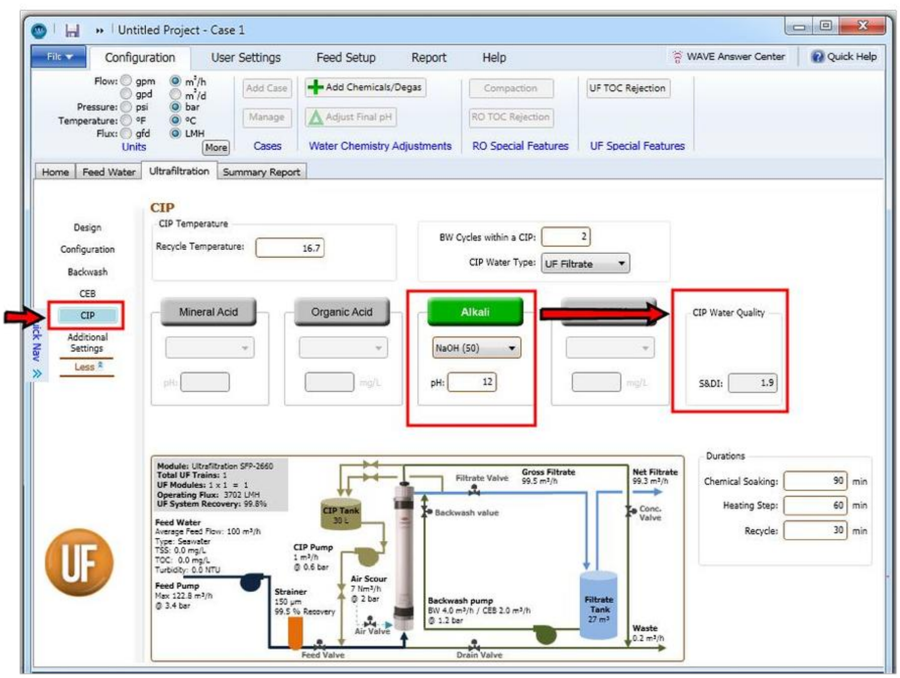


Figure 101. Changes Changes in Alkali input in CIP with feed TDS < 10,000 mg/L

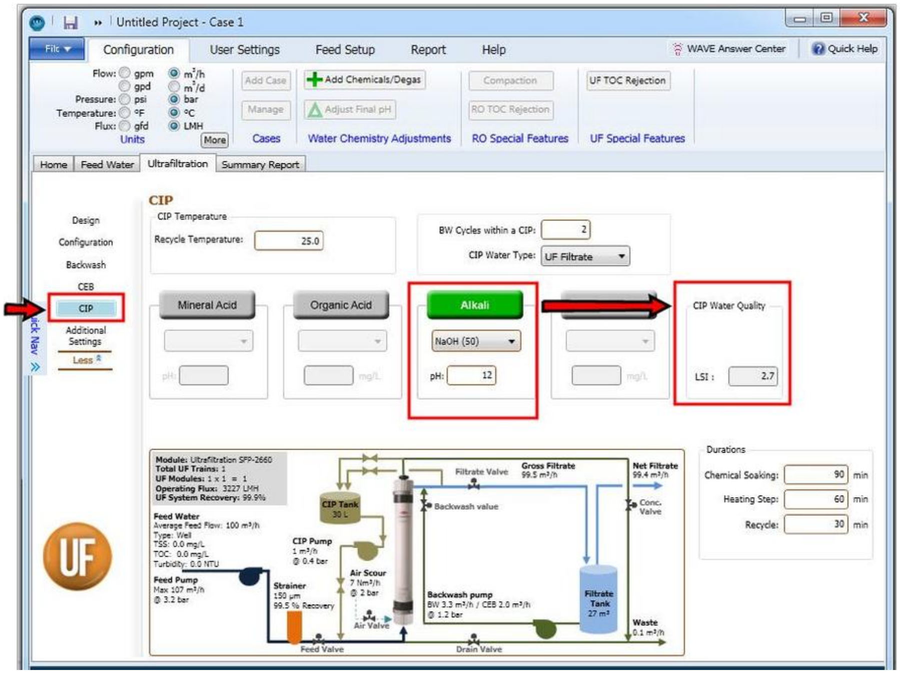


Figure 102. Changes in Alkali input in CIP with feed TDS > 10,000 mg/L

Notes:

- The list of alkali chemicals is defined by the user as described in Sections Chemical Library and Adding a New Chemical.
- The target pH in the CIP stream for pH reduction (if the ionic composition of the feed water is available) or target alkali concentration in the CEB stream interconvert automatically, i.e. if the user initially did not have ionic composition data and entered target alkali concentration, but later enters some ionic composition data, the target alkali concentration is converted to a corresponding pH and vice versa.
- If the "Alkali" button is activated, WAVE would require selection of an alkali and a corresponding pH/target concentration.
- Clicking on the "Alkali" button a second time would deactivate the input cell.

CIP Oxidant Selection and Dose Specification

WAVE allows for the addition of an oxidant for CIP. This is done by following the steps below (Figure 103):

1. Click on the "Oxidant" button to activate it. The grey area would turn green.
2. Click on the dropdown arrow.
3. Select the oxidant of interest.
4. Specify the target oxidant concentration in the CIP stream.
5. Click over or tab to move elsewhere in the CIP Window.

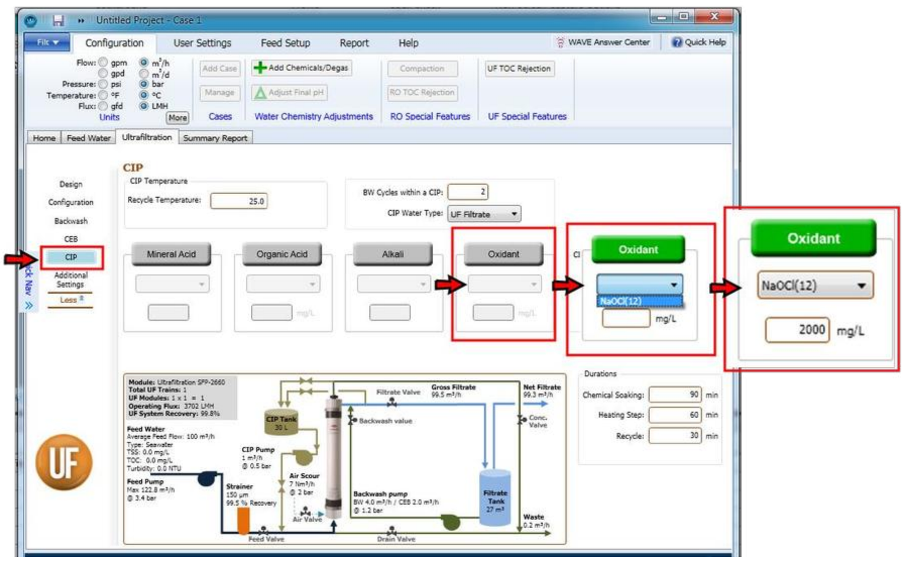


Figure 103. Specification of Oxidant for CIP (a) Activating the Oxidant option (b) Selecting the Oxidant (c) Specifying the target concentration in the CIP stream

UF System Diagram for CIP

The UF System Diagram is displayed in the CIP Window as shown in Figure 92 and Figure 103. Currently, the CIP changes would not be reflected in the UF System Diagram.

3.1.8 Specification of Additional UF Equipment Settings

In addition to the various ultrafiltration modes and the system configuration, WAVE allows the user to specify the following additional parameter values (as shown in Figure 104):

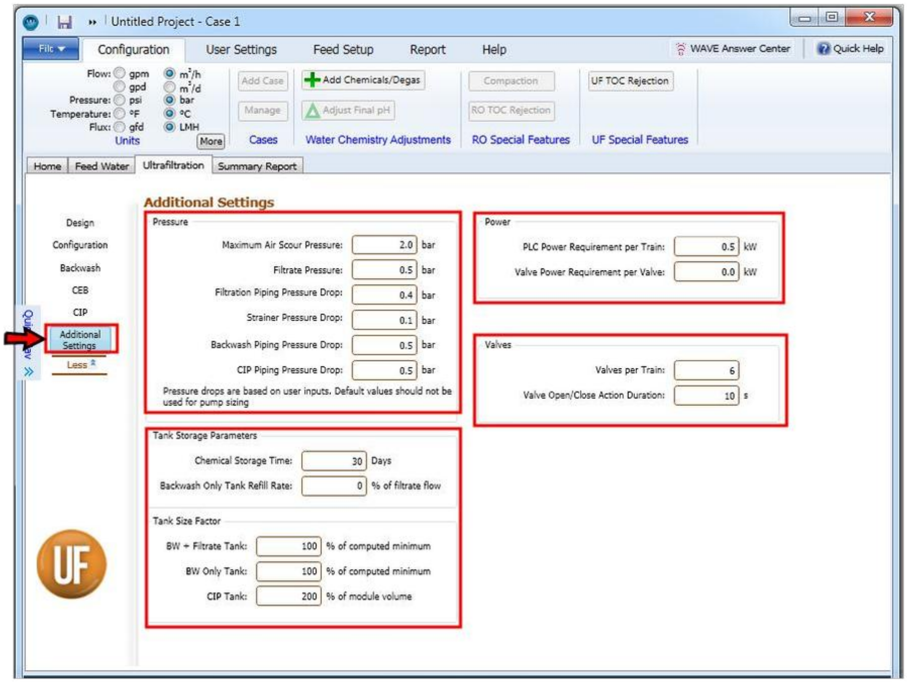


Figure 104. Additional equipment specifications for UF modeling in WAVE

Pressure Settings

WAVE allows the user to specify the following:

1. Maximum Air Scour Pressure
2. Filtrate Pressure
3. Filtration Piping Pressure Drop
4. Strainer Pressure Drop
5. Backwash Piping Pressure Drop
6. CIP Piping Pressure Drop

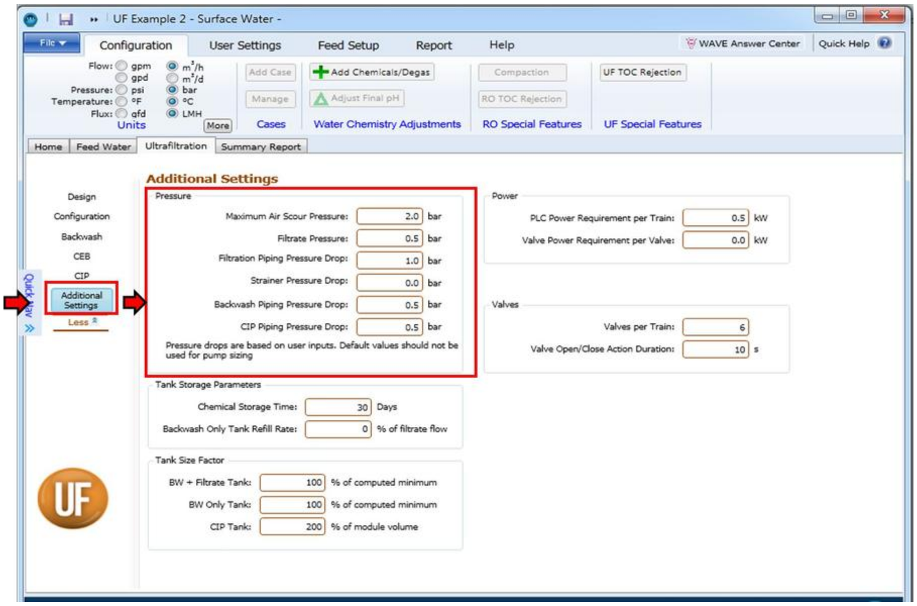


Figure 105. Additional equipment specifications for UF modeling in WAVE

Specifying these values allows the user to better approximate the energy requirement for the system operation.

Notes:

- Default filtrate pressures and piping pressure drops are 0.5 bar in WAVE for UF modeling.
- The default Maximum air scour pressure is 2 bar.

Power (Control Equipment Energy Consumption)

The UF control system contains multiple controllers, most of which would consume energy to operate. WAVE makes possible specification of the controller and valve power consumption as shown in Figure 106.

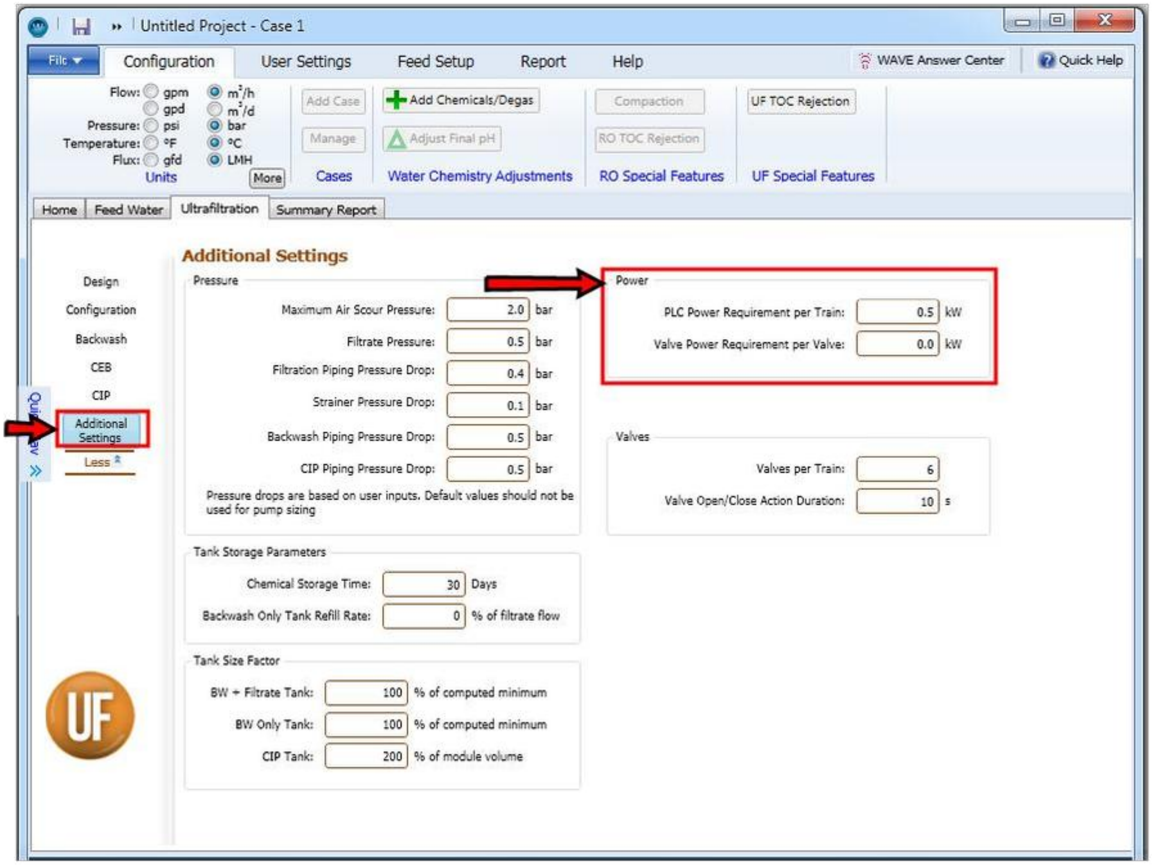


Figure 106. Additional equipment specifications for UF modeling in WAVE

Notes:

- The default PLC power requirement per train in WAVE for UF is 0.5 kW
- The default valve power requirement per train in WAVE for UF is 0.0 kW

Valve Timing

The valve open/close action durations of the multiple valves opening and closing in WAVE would affect the timing of downstream steps and are thus included in the WAVE UF modeling as shown in Figure 107.

Note: WAVE assumes 6 valves per train and a valve open/close action duration of 10 seconds by default.

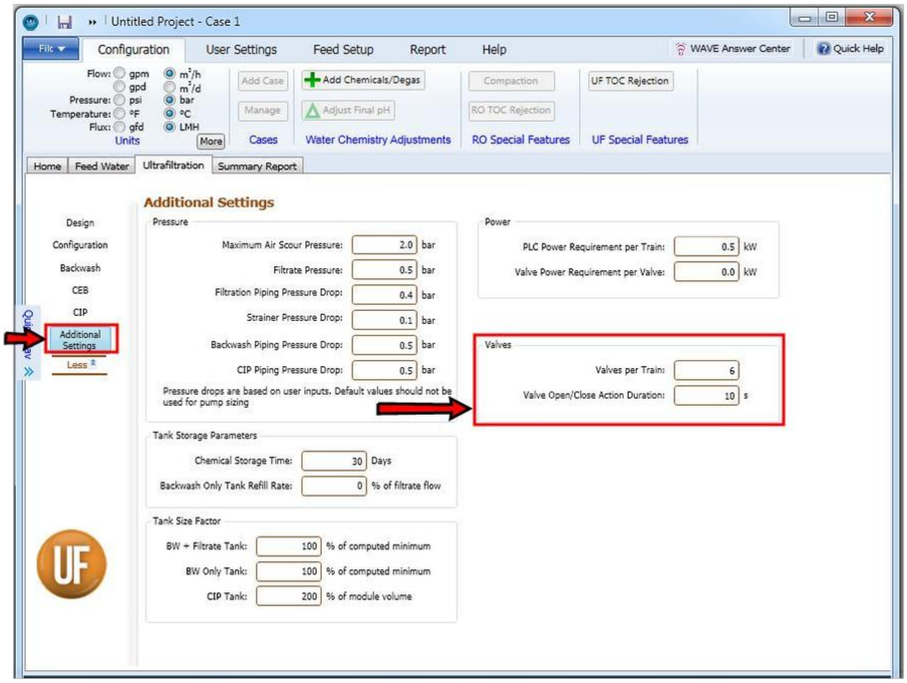


Figure 107. Additional equipment specifications for UF modeling in WAVE

Specification of Tank Sizes

WAVE makes possible the specification of actual tank sizes vs calculated minima in the Tanks Window as shown in Figure 108.

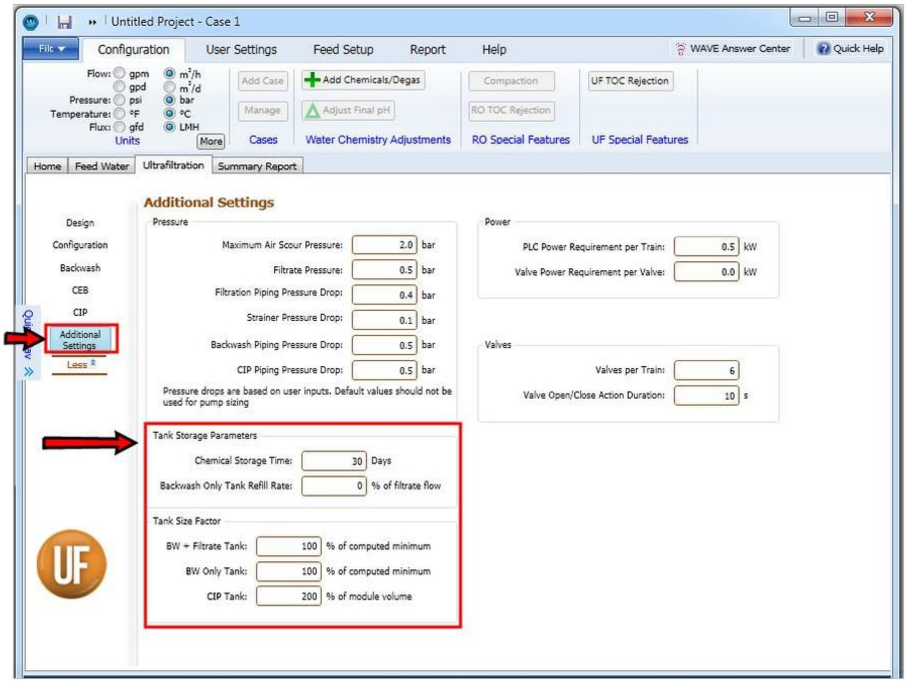


Figure 108. Tank specifications for UF modelling in WAVE

This includes:

1. Tank storage times and refill rates
    - By specifying how long the chemicals used are stored, given the rate of chemical consumption, WAVE can estimate the size of the chemical tanks.
    - In addition, given the Backwash tank refill rate, and the calculated Backwash flowrate, WAVE can calculate the size of the Backwash tank

2. Tank size factors
    - WAVE allows the user to specify how big a safety factor for the tanks the user needs as shown in Figure 108. Any changes to these entries would result in recalculation of the tank volumes shown in the UF System Diagram.
        - For the BW or BW+Filtrate tank, WAVE defaults to a value of 100% of the computed minimum tank size. This is based on an analysis of the flows into and out of the tank. A value <100% means the tanks could be undersized and a value of >100% provides a safety margin.
        - WAVE defaults to a CIP tank which is 200% of the module volume to be cleaned: 100% is the volume to fill the modules with cleaning solution, while the remaining 100% is assumed to fill the tank, pump, or pipes.

Note: A larger refill rate (larger % of filtrate flow directed to the tank) would fill up the tank faster.

3.2 ULTRAFILTRATION - FINAL CALCULATION AND REPORT GENERATION

Once the system design inputs are available in WAVE, WAVE can be run to model the system. The details of the following actions that can be performed to generate, modify and handle the reports are described below:

3.2.1 Generation and Understanding of Summary report

Once all the required inputs are in place in the Ultrafiltration Tab, the UF system can be simulated by clicking on the "Summary Report" Tab to generate the Summary Report and the "Detailed Report" button as shown in Figure 109.

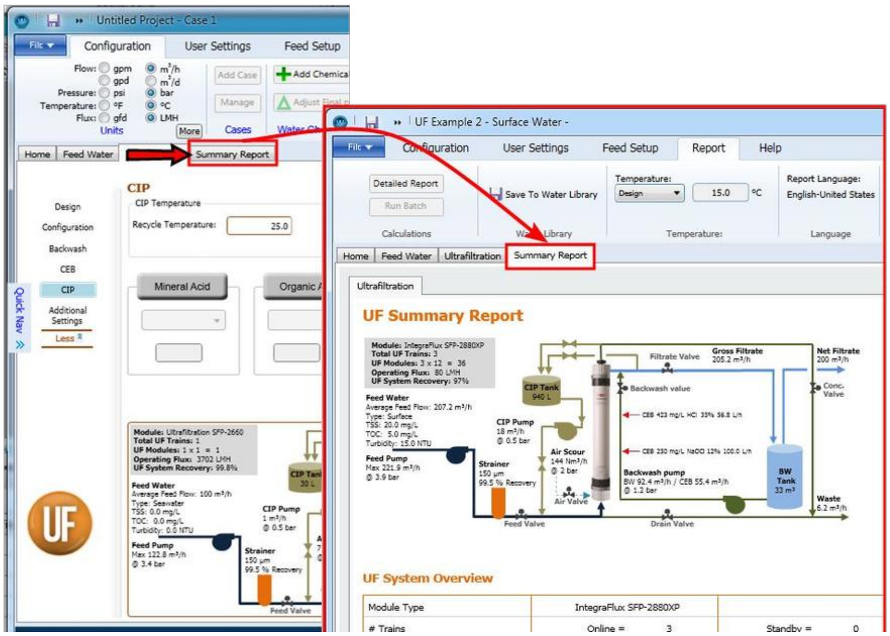
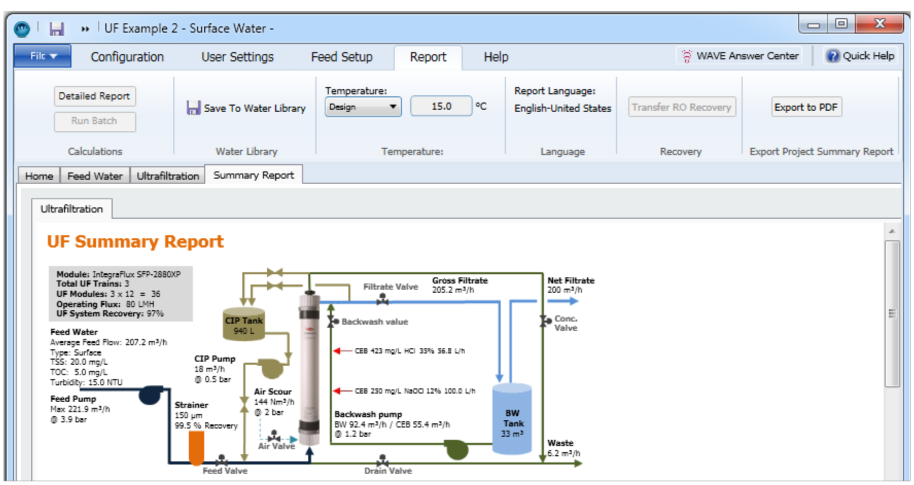


Figure 109. WAVE simulation and report generation for UF

In the Summary report the UF system diagram and some key output are described as shown below.



This table provides an overview of the UF system.

Ultrafiltration

UF System Overview

Module Type	IntegraPac IP-51XP	
# Trains	Online = 1	Standby = 0
# Modules	Per Train = 14	Total = 14
System Flow Rate (m³/h)	Gross Feed = 36.35	Net Product = 33.00
Train Flow Rate (m³/h)	Gross Feed = 36.35	Net Product = 33.00
UF System Recovery (%)	91.24	
TMP (bar)	0.43 @ 4.0 °C	0.31 @ 15.0 °C
Utility Water	Forward Flush: Pretreated water	Backwash: UF filtrate water

UF operating conditions are also specified, as presented in the table below (Results may vary depending on specific operating conditions).

UF System Overview

Module Type	IntegraFlux SFP-2880XP	
# Trains	Online = 3	Standby = 0
# Modules	Per Train = 12	Total = 36
System Flow Rate (m³/h)	Gross Feed = 207.22	Net Product = 200.00
Train Flow Rate (m³/h)	Gross Feed = 69.07	Net Product = 66.67
UF System Recovery (%)	97	
TMP (bar)	0.75 @ 5.0 °C	0.57 @ 15.0 °C
Utility Water	Forward Flush: Pretreated water	Backwash: UF filtrate water

These tables provide a quick view of the UF water quality.

UF Water Quality

Source		Wastewater (4.0 - 20.0 °C)	
		Feed	**Expected UF Product Water Quality**
Temperature	(°C)	15.0	15.0
Turbidity	(NTU)	5.9	≤ 0.1
Organics (TOC)	(mg/L TOC)	3.0	2.7
pH		7.2	7.2

UF Design Warnings

None

3.2.2 Generating and Understanding the UF Detailed Report

UF Detailed Report can be generated as shown below.

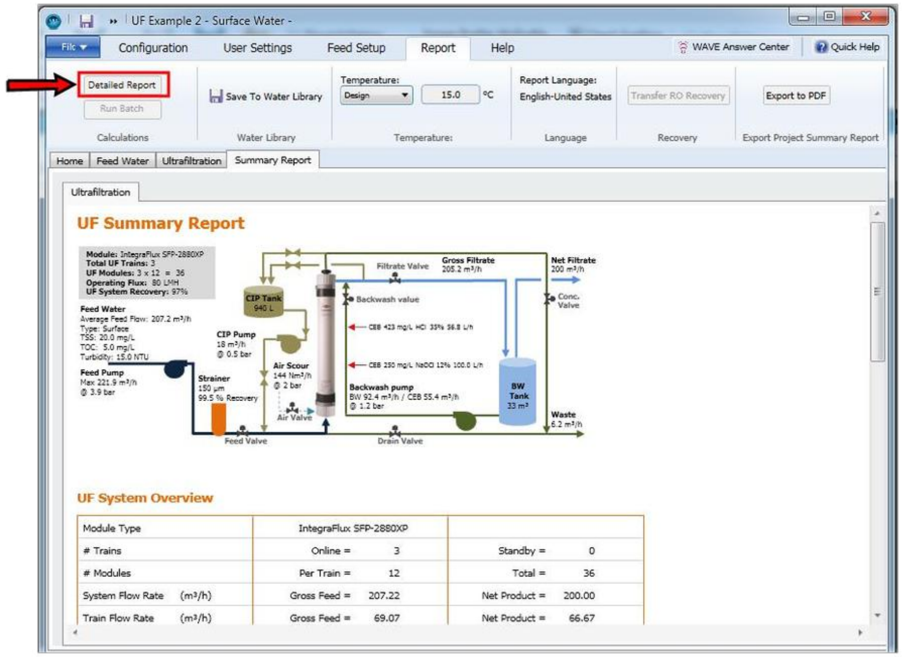


Figure 110. Generation of Detailed Reports in WAVE

Detailed Report Components are shown below. (Results may vary depending on specific operating conditions.)

UF System Overview

Module Type		IntegraFlux SFP-2880XP			
# Trains		Online =	3	Standby =	0
# Modules		Per Train =	12	Total =	36
System Flow Rate	(m^3/h)	Gross Feed =	207.22	Net Product =	200.00
Train Flow Rate	(m^3/h)	Gross Feed =	69.07	Net Product =	66.67
UF System Recovery	(%)	97			
TMP	(bar)	0.75 @ 5.0 °C		0.57 @ 15.0 °C	
Utility Water		Forward Flush:	Pretreated water	Backwash:	UF filtrate water

UF Operating Conditions

	Duration	Interval	Flux/Flow
Filtration:	50.0 min	53.6 min	-
Instantaneous			
3 Online Trains			80 LMH
3 Total Trains			80 LMH
Average			74 LMH
Net			72 LMH
Backwash	3.6 min	53.6 min	100 LMH
Acid CEB	16.3 min	336 hr	60 LMH
Alkali CEB	16.3 min	168 hr	60 LMH
CIP	313.3 min	90 day	1.50 m^3/h
Membrane Integrity Testing	0.0 min	24 hr	-

UF Water Quality

Source		Surface Water (5.0 - 40.0 °C)	
		Feed	Expected UF Product Water Quality
Temperature	(°C)	15.0	15.0
Turbidity	(NTU)	15.0	≤0.1
TSS	(mg/L)	20.0	-
Organics (TOC)	(mg/L TOC)	5.0	4.5
SDI	(%/min)	5.0	≤2.5
TDS	(mg/L)	180	193
pH		7.2	7.2

UF Configuration Options

Standby Option:	Constant module flux, variable plant filtrate flow
Storage Tank Option:	Storage Tank sized to maintain constant net filtrate flow
Forward Flush Water Source:	Pretreated water
BW/CEB Water Source:	UF filtrate water
CIP Water Source:	UF filtrate water

UF System Size and Module Details

Trains		Module Details		
		Name: IntegraFlux SFP-2880XP		
Online Trains	3	Membrane Area	77 m^2	829 ft^2
Standby Trains	0	Length	2.360 m	92.9 in
Max Offine Trains	1	Diameter	0.225 m	8.9 in
Total Trains	3	Weight (empty)	61 kg	134 lb
Modules/Train	12	Weight (water filled)	100 kg	220 lb
Total Modules	36	Water Volume	39.0 L	10.3 gal

UF Flow Details

UF Flow Details

Stream		Peak Flow	Average Flow
Feed (Gross)	(m³/h)	221.9	207.2
Feed Water Used for	(m³/h)		
Pretreatment	(m³/h)		1.0
Forward Flush & Process Streams	(m³/h)		1.0
Feed (Net)	(m³/h)	220.8	205.2
Filtrate (Gross)	(m³/h)	220.8	205.2
Filtrate Used for Cleaning	(m³/h)		5.2
Filtrate (Net)	(m³/h)		200.0
Air	(N m³/h)	144.0	
Backwash (BW)	(m³/h)	92.4	
Forward Flush Flowrate	(m³/h)	24.0	
CEB 1 (Acid)	(m³/h)	55.4	
CEB 2 (Alkali and/or Oxidant)	(m³/h)	55.4	
CIP Recycle	(m³/h)	18.0	
CEB HCl (35%) Metering Pump	(L/h)	56.8	
CEB NaOCl(12%) Metering Pump	(L/h)	100.0	
CIP HCl (35%) Metering Pump	(L/h)	18.5	
CIP Oxalic Acid(100%) Metering Pump	(L/h)	189.5	
CIP NaOH (30%) Metering Pump	(L/h)	13.9	
CIP NaOCl(12%) Metering Pump	(L/h)	259.7	

Footnotes:

* Maximum possible flow rate

UF Pump Hydraulics and Electrical Cost

Pump	Peak Flowrate (m³/h)	Average Pressure (bar)	Mechanical Power (kW)	Electrical Power (kW)	Energy (kWh/d)	Cost ($/d)
Feed	221.89	2.07	11.89	16.15	387.59	34.88
Backwash	92.40	1.21	3.10	4.22	5.65	0.51
CEB	55.44	0.73	1.12	1.52	0.01	0.00
HCl (35%) Metering Pump	0.06		0.00	0.00		
NaOCl(12%) Metering Pump	0.10		0.00	0.00		
CIP	18.00	0.50	0.25	0.34	0.02	0.00
HCl (35%) Metering Pump	0.02		0.00	0.00		
Oxalic Acid(100%) Metering Pump	0.19		0.00	0.01		
NaOH (30%) Metering Pump	0.01		0.00	0.00		
NaOCl(12%) Metering Pump	0.26		0.00	0.01		
CIP Solution Heating				0.00	0.00	0.00
Air Compressor	144.00	2.00	5.23	11.37	5.11	0.46
Electrical Valves				0.00	0.00	0.00
PLC and Instrumentation				1.50	36.00	3.24
Total Electrical Cost					434.39	39.10

UF Pressure Ratings

Process	T (°C)	TMP[a] (bar)	Fouling Max ΔP (bar)	Piping ΔP (bar)	Filtrate Pressure (bar)	Feed Pres.[b] (bar)	Pres. Rating (bar)	OK?[c]
Filtration								
Minimum Temp.	5.0	0.75	0.00	1.33	0.50	2.59	6.25	✓
Design Temp.	15.0	0.57	0.00	1.00	0.50	2.07	6.25	✓
Maximum Temp.	40.0	0.32	0.00	0.57	0.50	1.40	4.75	✓
BW	15.0	0.71	0.00	0.50		1.21	6.25	✓
CEB	15.0	0.43	0.00	0.30		0.73	6.25	✓
CIP	15.0			0.50		0.50	6.25	✓

Footnotes:

[a] At actual, average flux

[b] Sum of TMP, fouling ΔP, piping ΔP and filtrate pressure. Does not include pressure drop at the strainer.

[c] Comparison of Feed Pressure to Pressure Rating—a conservative comparison due to piping losses between the feed pump and module inlet.

Pressure drops are based on user inputs. Default values should not be used for pump sizing

UF Storage Tanks

Name	Bulk Conc. (%)	Minimum Recommended Volume (m^3)
Water[a]		33
CIP Tank		1
Chemical Storage[b]		
Hydrochloric Acid (HCl)	35%	0.006
Oxalic Acid ($C_2O_4H_2$)	100%	0.010
Sodium Hypochlorite (NaOCl)	12%	0.033
Sodium Hydroxide (NaOH)	30%	0.001

Footnotes:

[a] Storage tank sized to maintain constant net filtrate flow

[b] The mimimum recommended volume for chemical storage tanks is sized for 30 days of storage.

UF Design Warnings

None

Filtration Mode and Backwash Parameters

Normal Operation	Process Mode of Operation	Operating		Backwash (B/W)					Return to Operating[D]	Stop[E]
Operating Steps	Steps	1 Forward Flush at Start-up[D]	2 Filtration Mode	3 Air Inlet[C]	4 Drain	5 Backwash 1	6 Backwash 2	7 Forward Flush (F/F)	2 Filtration Mode	- Stop
Pump and Valve Conditions	Feed Pump	o	o					o	o	
	Backwash Pump					o	o			
	Chem. Dosing Pump[A]									
	CEB Dosing Pump									
	CIP Recycle Pump									
	Feed Valve	o	o					o	o	
	Filtrate Valve		o						o	
	Conc. Valve	o		o	o	o		o		
	Backwash Inlet Valve					o	o			
	Drain Valve				o		o			
	Air Inlet Valve			o						
	Duration	~2.0-3.0 min.	50.0 min.	20 s	30 s	30 s	30 s	45 s	50.0 min.	
	Flow Rate	2.0 m³/h	80 LMH	12.0 N m³/h	By gravity	100 LMH	100 LMH	2.0 m³/h	80 LMH	
Remarks	1. The filtration mode follows Steps 2-3-4-5-6-7-8. Backwash can be repeated several times according to the fouling degree of UF membrane modules. 2. The valve opening and closing time for each process step should be considered when programming is designed. 3. "o" = valve or pump is opened or operating.									
Footnotes	[a] Use of chemical dosing pump during backwash is based on feed water source and quality. Refer to DOW UF Design Guidelines. [b] Forward flush flow rate displayed on per-module basis. [c] Use of air scour and frequency is based on feed water source and quality. Air flow rate displayed on per-module basis. [d] May need to waste a portion of permeate to remove residual chemicals, depending on design and application. [e] If taken out of operation, add preservative and close all valves. Stop should occur only after backwash.									

CEB Parameters

CEB	CEB Mode of Operation	Operating	Chemically Enhanced Backwash (CEB)										Return to Operating[d]
Operating Steps	Steps	1 Filtration Mode	2 Air Inlet[b]	3 Drain	4 Backwash 1	5 Backwash 2	6 Soak	7 Air Inlet[b]	8 Drain	9 Backwash 1	10 Backwash 2	11 Forward Flush (F/F)[c]	1 Filtration Mode
Pump and Valve Conditions	Feed Pump	o										o	o
	Backwash Pump				o	o				o	o		
	Chem. Dosing Pump												
	CEB Dosing Pump[a]				o	o							
	CIP Recycle Pump												
	Feed Valve	o										o	o
	Filtrate Valve	o											o
	Conc. Valve		o	o	o			o	o	o		o	
	Backwash Inlet Valve				o	o				o	o		
	Drain Valve			o		o			o		o		
	Air Inlet Valve		o					o					
	Duration	50.0 min.	20 s	30 s	30 s	30 s	10.0 min.	20 s	30 s	30 s	30 s	45 s	50.0 min.
	Flow Rate	80 LMH	12.0 N m^3/h	By gravity	60 LMH	60 LMH	0.0 m^3/h	12.0 N m^3/h	By gravity	100 LMH	100 LMH	2.0 m^3/h	80 LMH
Remarks	1. Frequency of CEB is based on feed water source and quality. Refer to DOW UF Design Guidelines. 2. For a CEB, follow Steps 2-3-4-5-6-7-8-9-10-11. 3. "o" = valve or pump is opened or operating.												
Footnotes	[a] Chemicals and concentrations used during CEB are based on feed water source and quality. Refer to DOW UF Design Guidelines. [b] Air flow rate displayed on per-module basis. [c] Forward flush flow rate displayed on per-module basis. [d] May need to waste a portion of permeate to remove residual chemicals, depending on design and application.												

CIP Parameters

CIP	CIP Mode of Operation	Oper.	Backwash (B/W)[b]				CIP[c]				Backwash (B/W)[b]				Return to Oper.[g]
		1	2	3	4	5	6	7	8	9	10	11	12	13	1
	Steps	Filtration Mode	Air Inlet[a]	Drain	Backwash 1	Backwash 2	Drain	CIP Recycle[d]	Soak[e]	CIP Recycle[d]	Drain	Backwash 1	Backwash 2	Forward Flush (F/F)[f]	Filtration Mode
Pump and Valve Conditions	Feed Pump	o												o	o
	Backwash Pump				o	o						o	o		
	Chem. Dosing Pump														
	CEB Dosing Pump														
	CIP Recycle Pump							o		o					
	Feed Valve	o												o	o
	Filtrate Valve	o													o
	Conc. Valve		o	o	o		o		o		o	o		o	
	Backwash Inlet Valve				o	o						o	o		
	Drain Valve			o		o	o				o		o		
	Air Inlet Valve		o												

Remarks

1. Frequency of CIP is 1-3 months, adjusted according to operating conditions.
2. Start CIP with backwash sequence; complete CIP with backwash sequence.
3. CIP is done manually.
4. "o" = valve or pump is opened or operating.

Footnotes

[a] Air flow rate displayed on per-module basis.
[b] This step should be repeated 3-8 times.
[c] This step and duration is shown for a single chemical cleaning. If acid and base cleaning are both required, repeat Steps 6-13.
[d] CIP recycle flow rate displayed on a per-module basis.
[e] The duration of this step might be longer, up to overnight (12 hours), if the fouling is severe.
[f] Forward flush flow rate displayed on per-module basis.
[g] May need to waste a portion of permeate to remove residual chemicals, depending on design and application.

UF Utility and Chemical Costs

Service Water

	Average Flowrate (m^3/h)	Unit Cost ($/m³)	Unit Cost ($/h)	Cost ($/d)
Non-Product Feed Water	6.19	0.14	0.87	20.79
Waste Water Disposal	6.19	0.69	4.27	102.46
Total Service Water Cost				123.25

Electricity

Peak Power	(kW)	31.75
Energy	(kWh/d)	434.39
Electricity Unit Cost	($/kWh)	0.09
Electricity Cost	($/d)	39.09
Specific Energy	(kWh/m³)	0.09

Chemicals

Chemical	Unit Cost ($/kg)	Dose (mg/L)	Volume (L/d)	Cost ($/d)
HCl (35%)	0.100		0.20	0.02
CEB1		423		
CIP		423		
NaOCl (12%)	0.330		1.11	0.42
CEB2		250		
CIP		2000		
NaOH (30%)	0.260		0.02	0.01
CIP		307		
Oxalic Acid (100%)	0.940		0.33	0.58
CIP		20000		
Total Chemical Cost				1.04

Utility and Chemical Cost	($/d)	163.39
Specific Water Cost	($/m³)	0.03

3.2.3 Modification of System Design after Calculation

WAVE makes possible regeneration of the report through:

Modification of the Feed Temperature

After the first simulation of the system, a WAVE user can rerun the simulation at a different temperature by following these steps (Figure 111):

1. Click on the dropdown arrow under "Temperature" in the Summary Report Tab.
2. Select the appropriate temperature value:
    a. Design temperature
    b. Maximum temperature
    c. Minimum temperature
    d. Other values (using the 'Specify') option.
3. Click on the "Report" button.

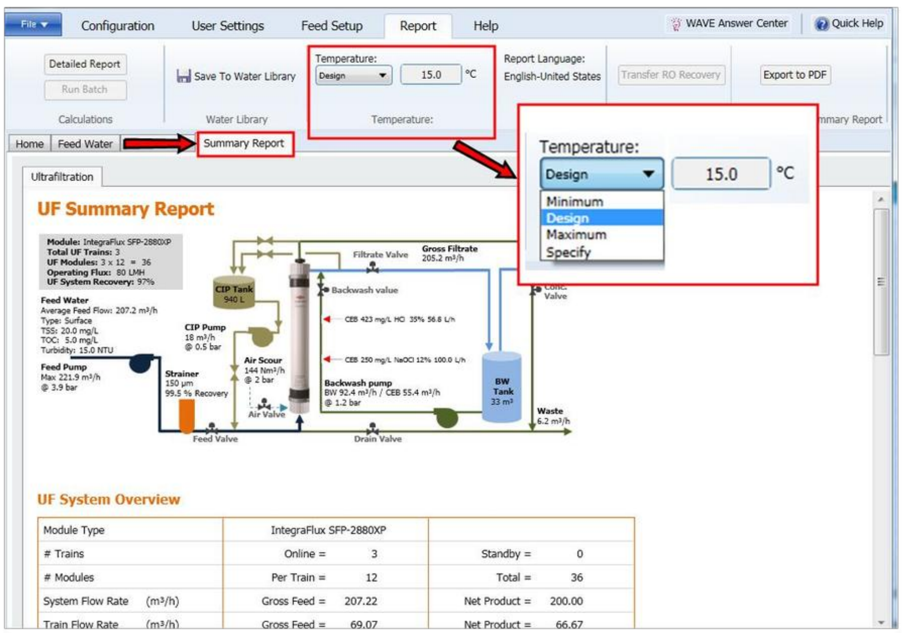


Figure 111. WAVE report regeneration and addition simulation by changing feed temperature (a) Selection of the appropriate temperature (b) Initiation of calculation

4. The report will be updated with recalculated values.

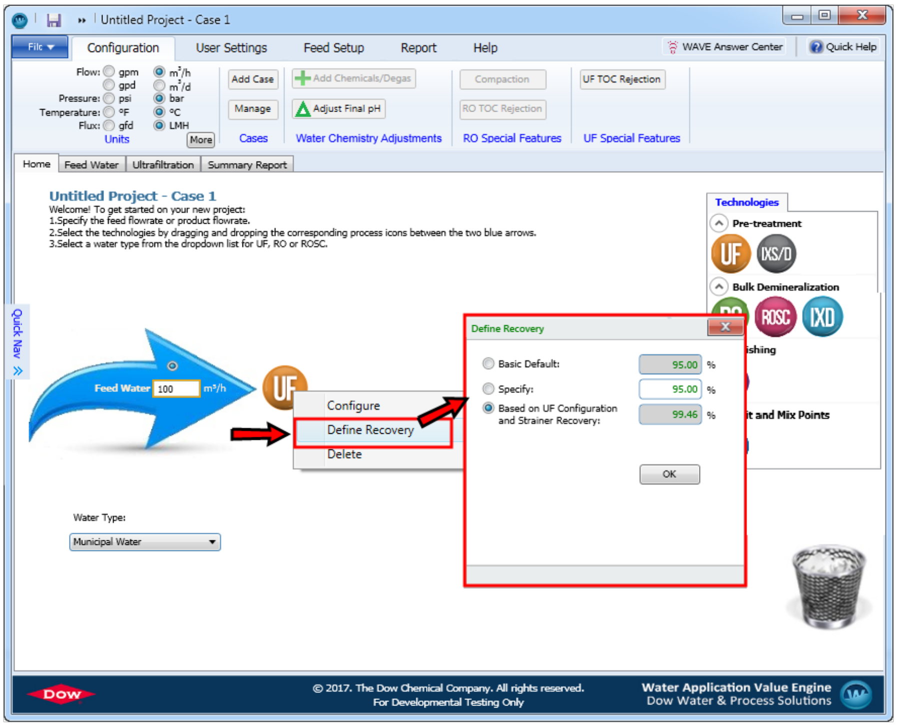
Notes:

- The same Minimum, Maximum and Design Temperatures specified in the Feed Water Tab would be shown in the dropdown list in the Report Tab.
- The temperature specified at this step would not be propagated to other windows (e.g. the Chemical Adjustment Popup Window)

Modification of the System Recovery

WAVE makes it possible to send the System Recovery calculated at the Report Tab to the Home Tab to be used for additional work. This can be done through the following steps (as shown in Section Defining the Feed Water Flowrate and Recovery):

1. Click on the "Update Estimated Recovery" button in the Report Tab.
2. Click on the Home Tab and right-click on the Technology symbol
3. Select "Define Recovery" from the dropdown list. The Define Recovery Popup Window would appear.
4. Select the radio button next to "Use Last Calculated Value" and click "OK"
5. Click on the Report Tab



Note: The "Update Estimated Recovery" button only updates the System Recovery.

3.2.4 Handling the Reports (Saving and Exporting)

The Summary Report serves as a quick look at the results. The Summary Report can be exported as a PDF document to a folder location of the user's choice Figure 112.

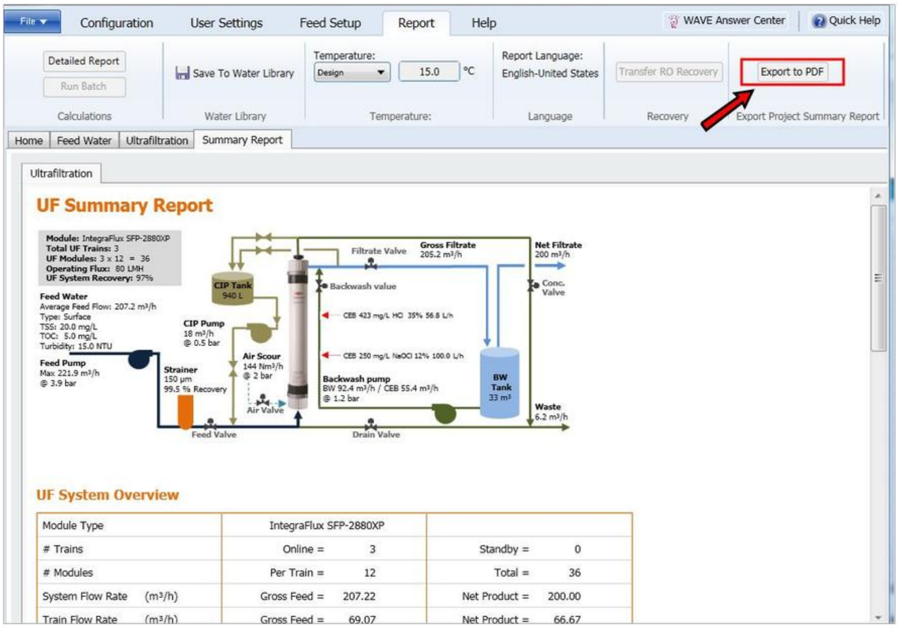


Figure 112. Export of Summary Report in WAVE as PDF

The reports can be exported to PDF or to Excel, Word or PDF as shown in Figure 113 and Figure 114. All of these options lead to a folder location where the user can save the PDF, Excel or Word file.

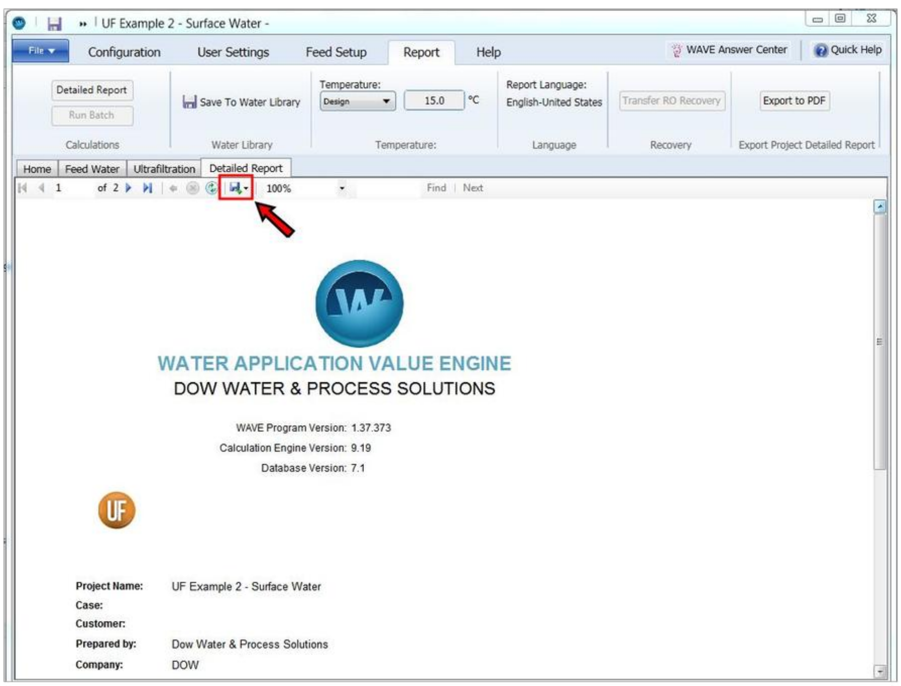


Figure 113. Export of Detailed Reports in WAVE - selecting the dropdown

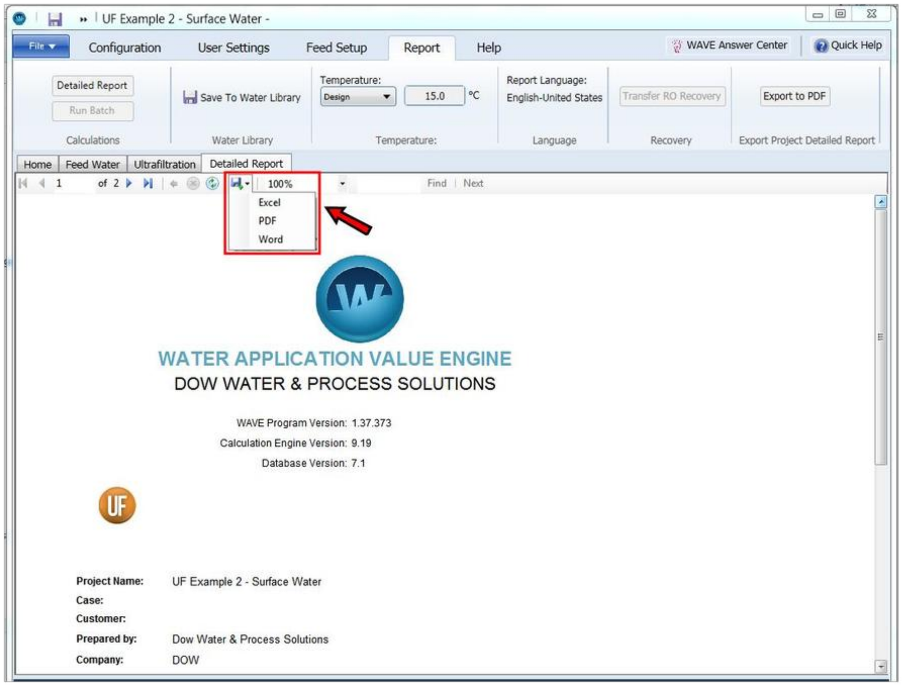


Figure 114. Export of Detailed Reports in WAVE - selecting the option

4 Reverse Osmosis

4.1 Reverse Osmosis and Nanofiltration system specification

RO/NF/ROSC system specification includes the following steps:

4.1.1 Adding RO/NF/ROSC icon into the WAVE Home Window

The RO Symbol can be dragged and dropped on top of the gray spot to specify an RO/NF process as shown in Figure 115. The same applies for the ROSC. If the gray spot is not visible, simply dragging the RO icon between the two large blue arrows will make the gray spot visible.

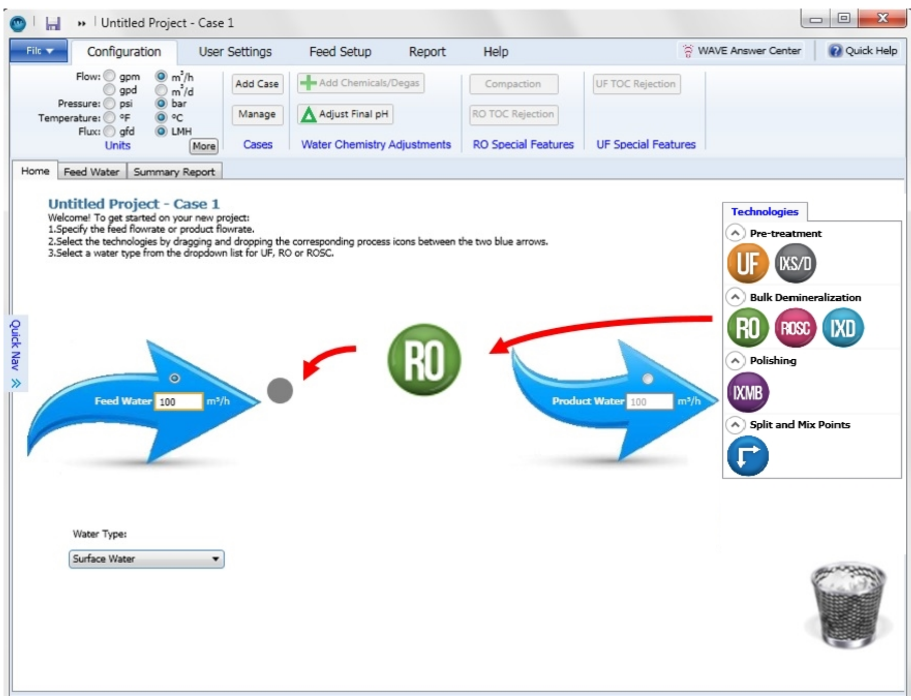


Figure 115. Dragging and dropping RO icon

- **RO** stands for Reverse Osmosis. With this option 8 inch elements designs can be performed
- **ROSC** stands for Reverse Osmosis Small Commercial. Wwith this option 4 inch and smaller elements designs can be performed
- **NF** stands for Nanofiltration. With this option different sizes NF elements designs can be performed

Notes:

- WAVE does not allow the inclusion of both RO and ROSC in the same system design.
- WAVE allows only one of RO or ROSC in a system design.

4.1.2 Removing RO/NF/ROSC Process Icon from the WAVE Home

There are two ways to remove the RO/NF/ROSC process icons as shown in Figure 116 and Figure 117:

1. Dragging and dropping the icons into the picture of the waste bin

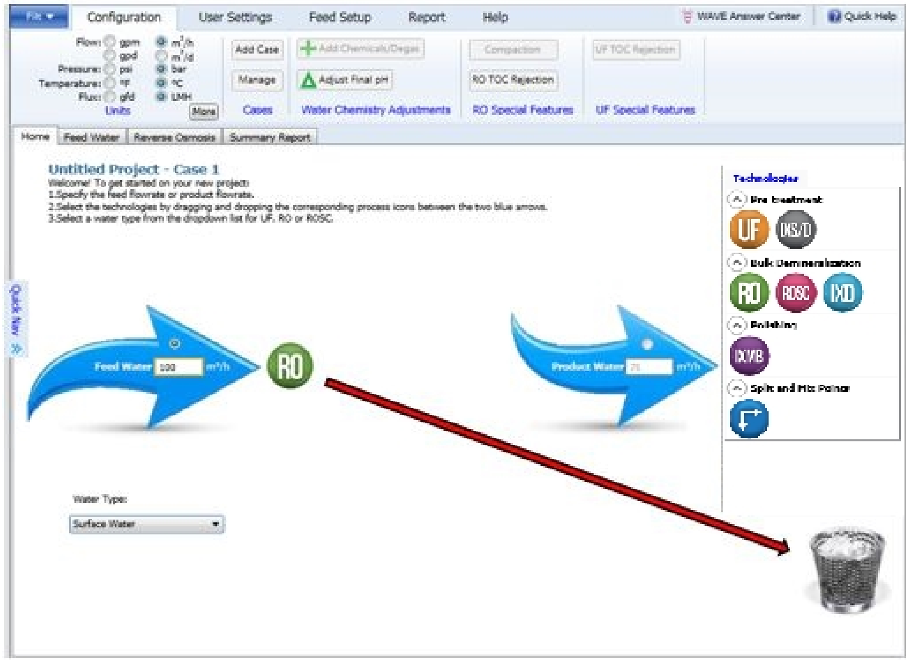


Figure 116. Removing an RO icon by dragging and dropping onto the waste bin

2. Right-clicking on the icon in question and selecting "Delete"

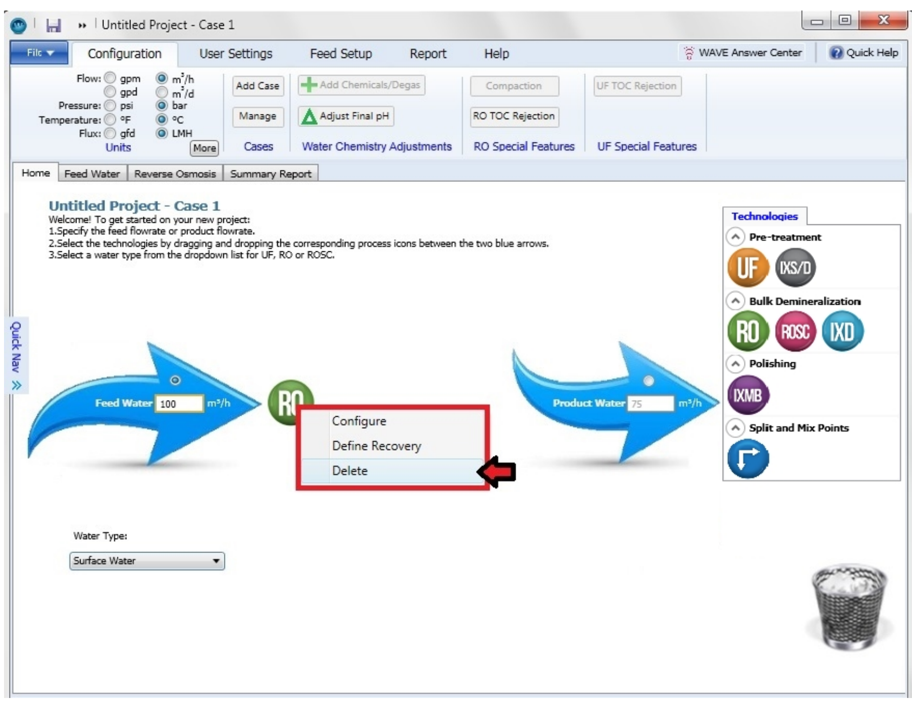


Figure 117. Removing an RO icon by right-clicking and selecting "Delete"

4.1.3 Defining the Feed Water Flowrate and System Recovery

Feed and product water flowrates can be specified using the text boxes in the middles of the blue arrows as shown below. First, Feed or Permeate flow option should be selected using the radio button in the upper part of the arrow, later the flowrate can be specified.

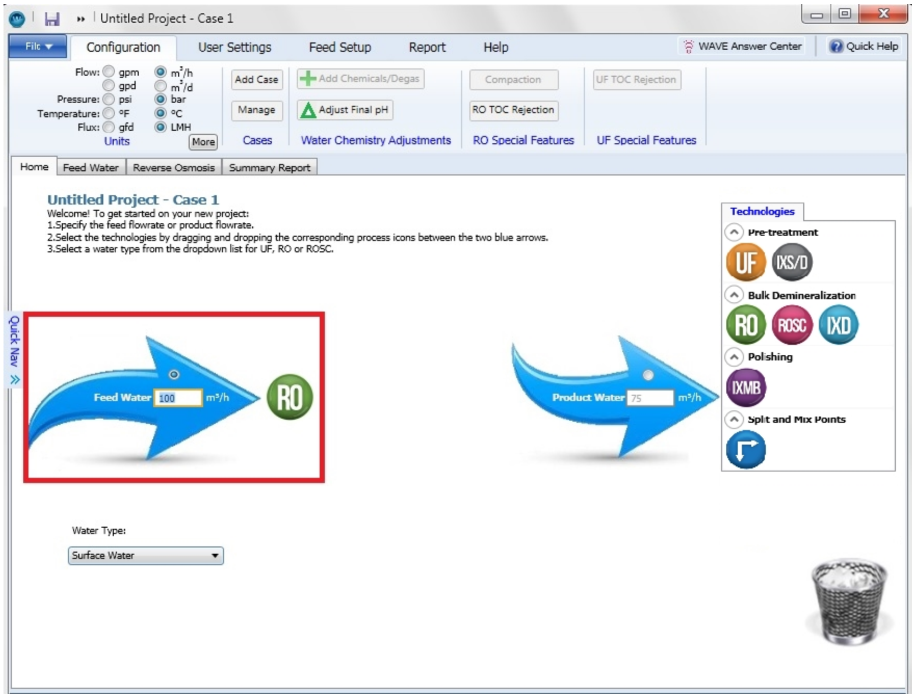


Figure 118. Definition of feed or product flow for an RO system

Notes:

- WAVE would display a warning if the Feed or Product flowrates are specified as 0 or a negative number
- Given a feed water flowrate, WAVE would calculate a product flowrate based on a default recovery. Given a product water flowrate, WAVE would calculate a feed flowrate based on a default recovery
- WAVE does not allow simultaneous specification of the feed and product flowrates

- WAVE does give the user the possibility of defining a recovery that defines feed/product flow if product/feed flow is known (shown in Figure 119).

  This is done by:

  1. Right-clicking on the RO/ROSC icon
  2. Selecting "Define Recovery"
  3. Entering the desired recovery
  4. Clicking "OK"

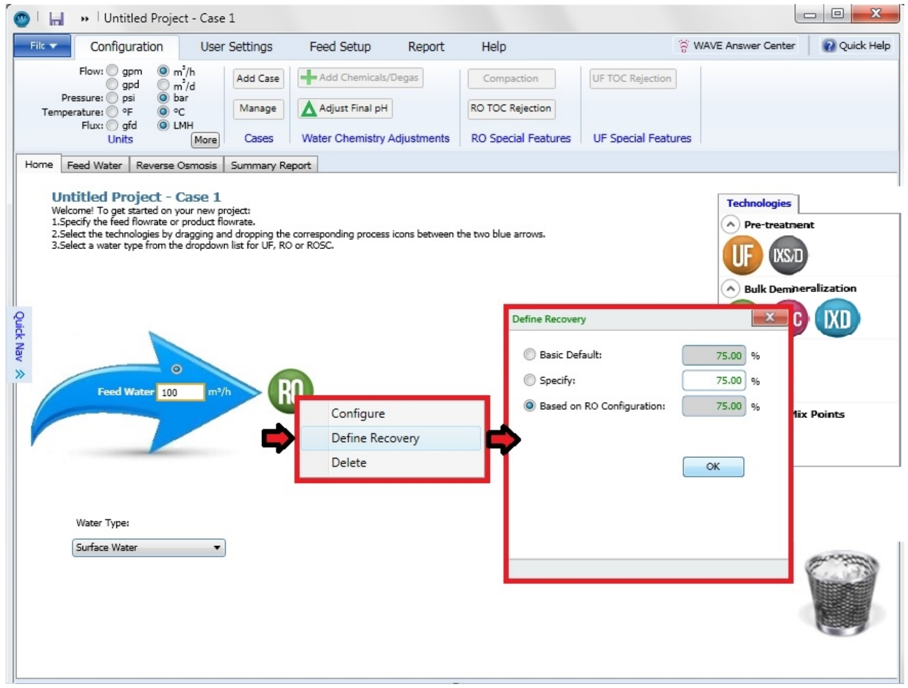


Figure 119. Definition of recovery for an RO/ROSC system in the Home page

The default recovery value for RO & ROSC systems is 75% in WAVE. The recovery defined above is a system recovery, not necessarily a stage/pass recovery.

Additional Information: System Design Guidelines

4.1.4 Defining the feed water type and composition

Please refer to section Defining the Feed Water Composition for UF.

4.1.5 Defining the RO/NF/ROSC System Configuration

The Number of Passes

WAVE provides the option of adding a pass to set up a two-pass system. By default, every RO/NF/ROSC system would be a single pass system. The additional pass can be added as shown below:

Click on "Add Pass" as shown in Figure 120.The additional pass (Pass 2) can be removed by:

1. Select the second pass (Pass 2)
2. Click on the red oval beside the Pass 2 button as shown in Figure 120.

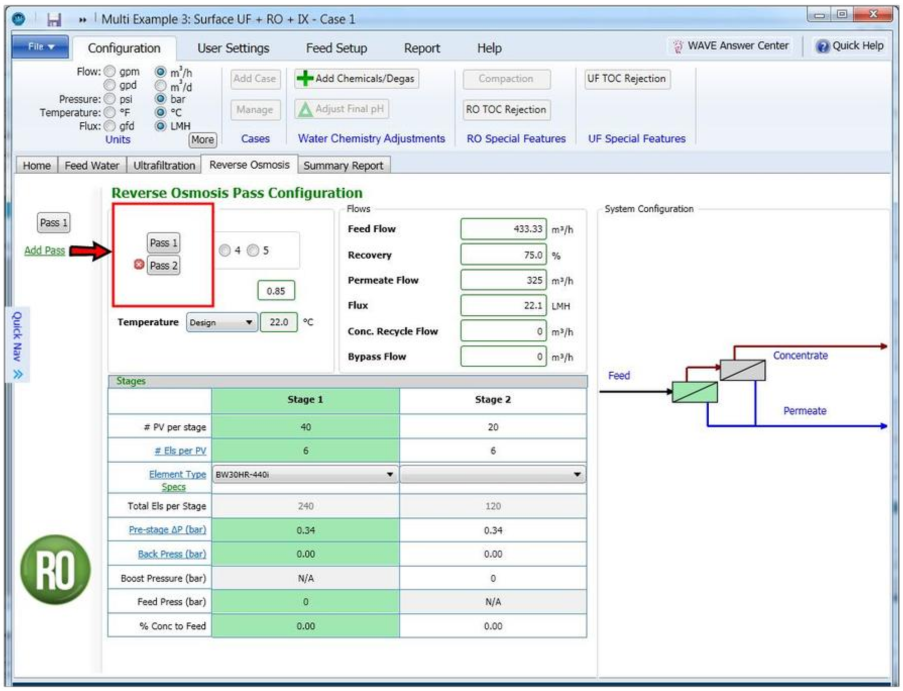


Figure 120. Adding and removing passes in RO system

Notes:

- Once a second pass (Pass 2) is defined, the "Add Pass" button becomes inactive. It would be reactivated if Pass 2 is deleted
- It is not possible to delete Pass 1

Additional Information : Select the flow configuration and number of passes

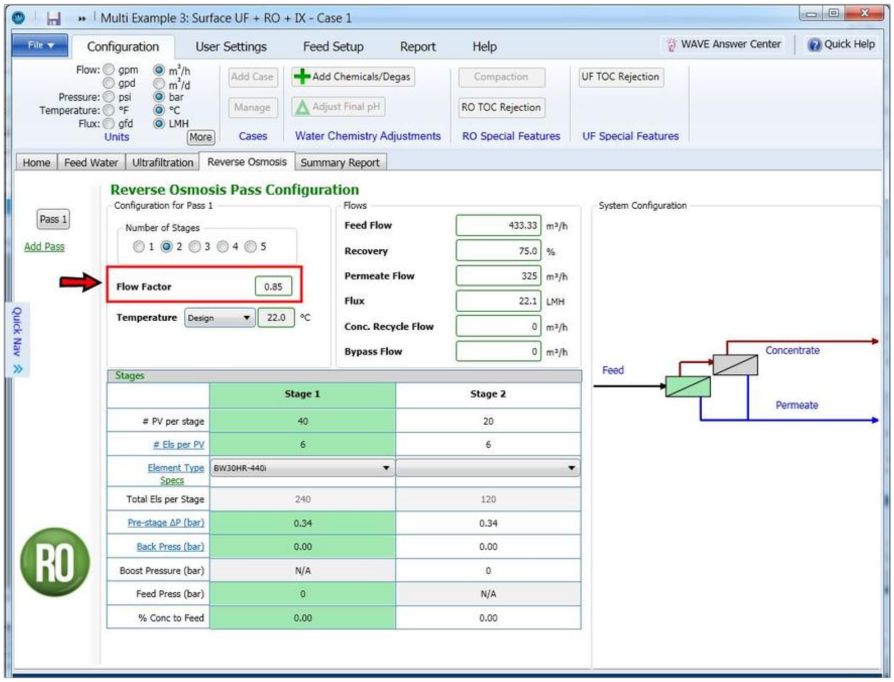
The Flow Factor

The Flow Factor is used in WAVE to account for flow loss due to fouling. It can be specified for each pass as shown below in Figure 121:

1. Click on the Pass of interest (Pass 1 or Pass 2)

   Update the Flow Factor

   Note: The Flow Factor must be between 0 and 2.



2. 0

Figure 121. Specification of Flow Factor

The Number of Stages

One can specify up to 5 stages for each pass. By default WAVE assigns a single stage per pass. The number of stages can be specified for each pass as shown below in Figure 122:

1. Click on the Pass of interest (Pass 1 or Pass 2)
2. Update the Number of Stages. Note the change in the Process Flow Diagram and Table.

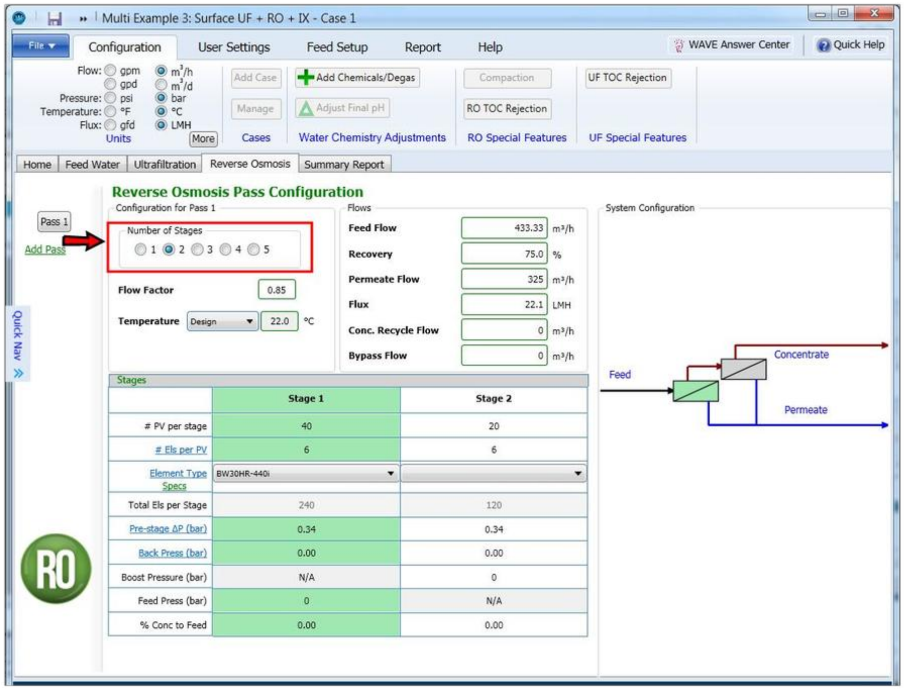


Figure 122. Specification of the Number of Stages in WAVE

Note: WAVE users can click on each box corresponding to a stage in the RO/NF/ROSC Process Flow Diagram and the corresponding column in the table would be highlighted. By default, the 1st element (thus the 1st column in the table) is highlighted.

Additional Information : Select the Number of Stages

Specifying Elements, Number of Pressure Vessels and Elements per Pressure Vessel Standard Design

In WAVE one can specify the RO/NF/ROSC elements to be used in each stage, the number of pressure vessels in each stage and the number of elements per pressure vessel. The number of pressure vessels in each stage and the number of elements per pressure vessel can only be specified from the Reverse Osmosis Tab. By default, both of these values are 1.

There are two ways of specifying the RO/NF/ROSC elements to be used in each stage.

1. Specifying the elements using the Drop down list
2. Specifying the elements using the Element Specifications Pop-up Window

1. Specifying the RO/NF/ROSC elements using the Drop down list

One can specify the RO/NF/ROSC elements to be used in each stage, the number of pressure vessels in each stage and the number of elements per pressure vessel as shown in Figure 123.

1. Click on the Pass of interest (Pass 1 or Pass 2)
2. For each stage, click on the dropdown box under "Element Type"
3. Select the appropriate element
4. Update the number of pressure vessels and the number of elements per pressure vessel for each stage

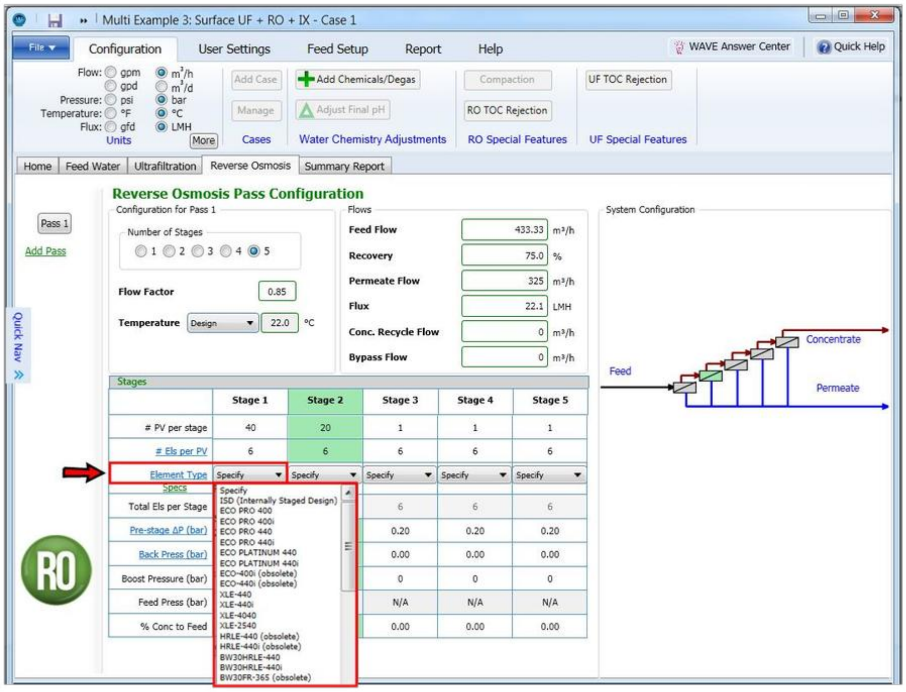


Figure 123. Specification of the RO/NF/ROSC elements, number of pressure vessels and number of elements per pressure vessel for each stage in the Reverse Osmosis Tab in WAVE

2. Specifying RO/NF/ROSC elements using the Element Specifications Pop-up Window

One can specify the RO/NF/ROSC elements from the Element Specifications Pop-up Window as shown below and in Figure 124.

1. Click on the Pass of interest (Pass 1 or Pass 2).
2. Click on "Specs" under the Element Type row header.
3. For each stage, click on the dropdown box under "Element Type". The Element Specifications Pop-up Window will appear.
4. Double click on the appropriate element.

5. Close the Element Specifications Pop-up Window by clicking on the red box at the top right corner or clicking on 'Close Window".

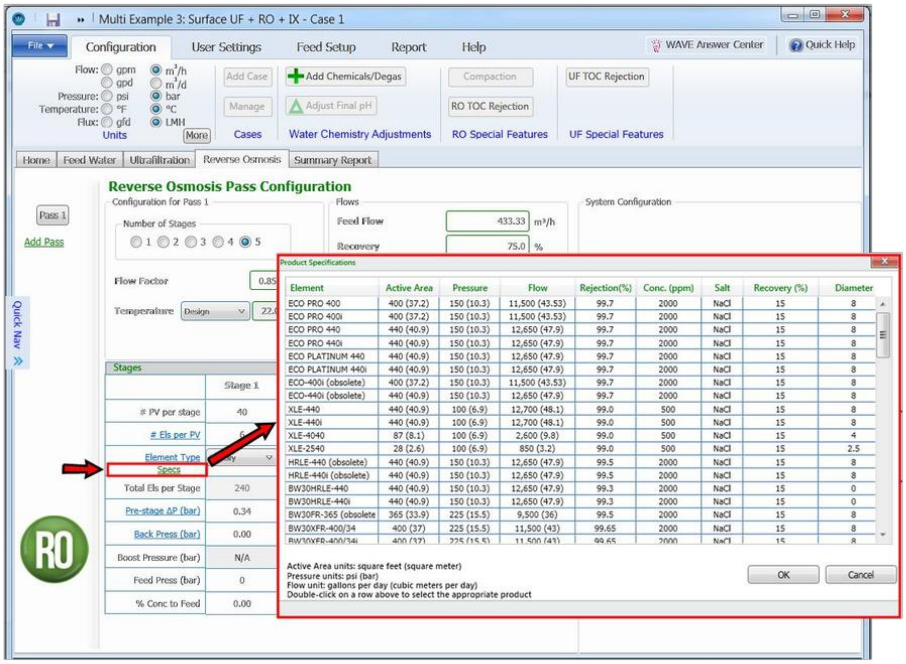


Figure 124. Specification of the RO/NF/ROSC elements from the Element Specifications Pop-up Window in WAVE

Notes:

- Selecting an element by double-clicking on the appropriate element in the Element Specifications Pop-up Window will apply for every stage in the pass. If different elements are desired for the different stages, the user must individually select the appropriate elements for each stage.
- Once an element is selected in the table in the Reverse Osmosis Tab, the same element is used as default in all the downstream stages in the Pass unless specified otherwise.

Additional Information :

FILMTEC" Elements

Select the Number of Elements, Pressure Vessels

Internally Staged Design (ISD)

WAVE allows the specification of different elements within a pressure vessel; essentially creating stages within a stage. This is called Internally Staged Design or ISD. The following steps can be used for ISD:

1. Click on the Pass of interest (Pass 1 or Pass 2)

2. For the stage of interest, click on the dropdown box under "Element Type"

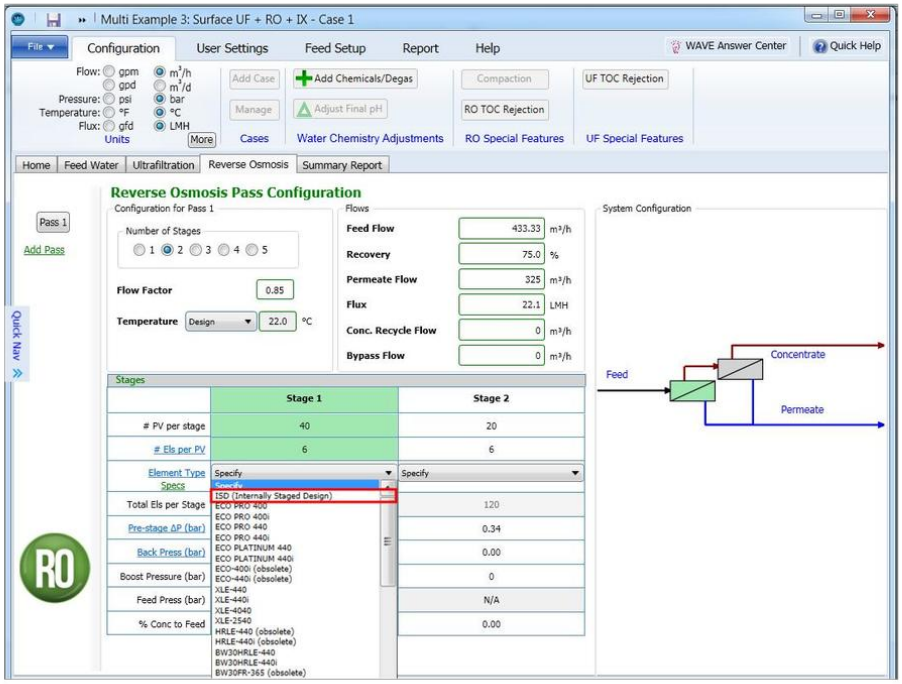


Figure 125. Specification of ISD in WAVE (a) Selection of the ISD option (b) Selection of the element in the first position (c) Selection of the element in an intermediate position (d) Finalizing the ISD

3. Select "ISD". The ISD Specification Pop-up Window will appear.

4. Select the appropriate element for the first position (Element 1). WAVE would use the selected element as the default selection. The ISD Specification Pop-up Window will be filled with information on the selected element.

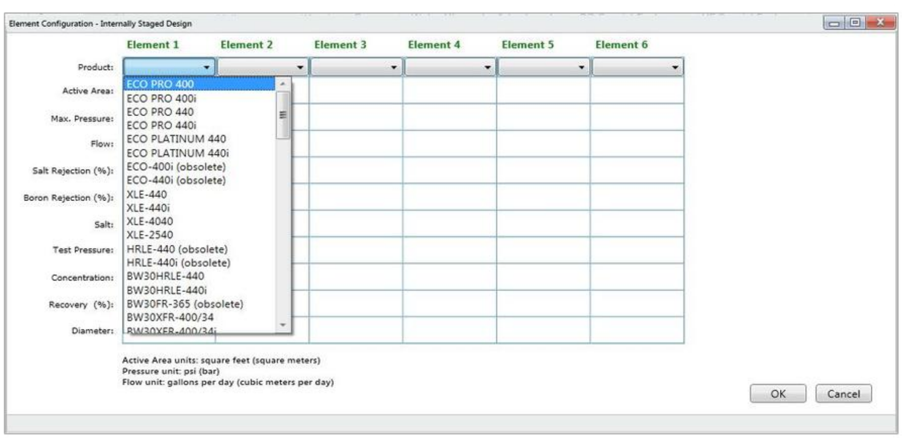


Figure 126. Edition of the ISD Specification Pop-up Window

5. Select the appropriate element for the rest of the positions (2nd, 3rd etc.). WAVE would identify each element with a different color.
6. A user can modify an ISD by clicking on the "Edit ISD" as shown in Figure 125 and Figure 126. The Specification Pop-up Window will appear.

Notes:

- WAVE would not allow the user to specify an element in any other position unless he/she specifies the element in the first position in ISD.
- WAVE allows the user to specify a different element for every position in an ISD. However, the elements must have the same diameter.
- WAVE allows the user to specify an ISD for every stage.
- One can remove an ISD design by selecting an element in the Reverse Osmosis Tab instead of ISD.
- Once an element is selected in the ISD window, the same element is used as default in all the downstream positions in the pressure vessel unless specified otherwise.
- One can specify an ISD design in WAVE even if there is only one element in the pressure vessel.
- WAVE users can tell which stages are ISD either from the table in the Reverse Osmosis Tab or by hovering their mouse cursor over the relevant box in the RO/NF/ROSC Process Flow Diagram.

4.1.6 Specifying Feed Pressure, Boost Pressure, Back Pressure and Pre-stage Pressure Drop

The different pressure specifications for the RO/NF/ROSC system can be incorporated in WAVE as shown in Figure 127. The default values for Feed Pressure, Feed Pressure and Feed Pressure are all 0, while the default pre-stage pressure drop is 0.34 bar (5 psi).

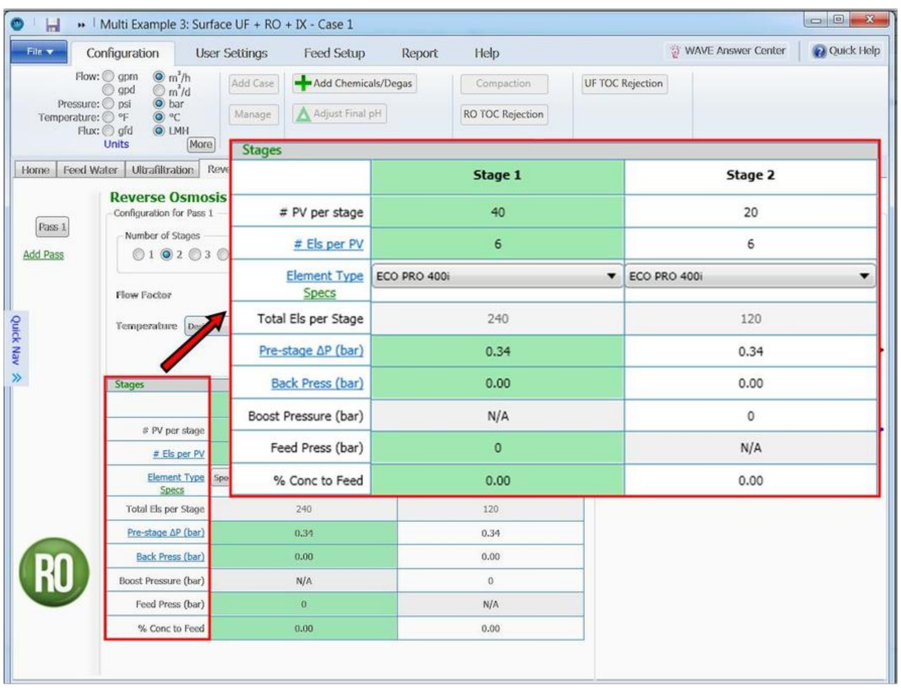


Figure 127. Specification of Feed Pressure, Boost Pressure, Back Pressure and Pre-stage Pressure Drop

Notes:

- WAVE users can tell how much Feed Pressure, Boost Pressure and Back Pressure were applied from the table in the Reverse Osmosis Tab or by hovering their mouse cursor over the relevant symbol in the
- RO/NF/ROSC Process Flow Diagram.
- If the Feed Pressure is specified in WAVE, then the user would not be able to specify a recovery for the
- RO/NF/ROSC system. Even though WAVE allows the user to specify a recovery value in the Home Tab (for a system including only RO/NF/ROSC), the Calculation Engine would ignore the specified recovery value.
- WAVE allows the user to specify a Feed Pressure for one pass and a recovery for another pass.
- WAVE allows the user to specify different Feed Pressures for each pass.
- WAVE allows specification of Feed Pressure only for the 1st stage in each pass (even ISD).
- WAVE does not allow the specification of Boost Pressure for the 1st stage in each pass, as it is assumed that any boost needed is included in the Feed Pressure.

4.1.7 Specifying Recovery

In WAVE, the RO/NF/ROSC recovery can be defined at two levels:

Recovery for the Entire System

The recovery for the RO/NF/ROSC system can be defined in one of two ways:

1. RO/NF/ROSC system recovery definition at the Home Tab
2. RO/NF/ROSC system recovery definition at the Flow Calculator Pop-up Window

a. RO/NF/ROSC system recovery definition at the Home Tab

If the only process modeled in WAVE is RO/NF/ROSC, the Recovery for the RO/NF/ROSC system can be defined as follows (shown in Figure 128):

1. Click on the Home Tab.
2. Right-click on the RO or ROSC icon and select "Define Recovery".
3. Select the "Specify" radio button and put in the appropriate Recovery value.

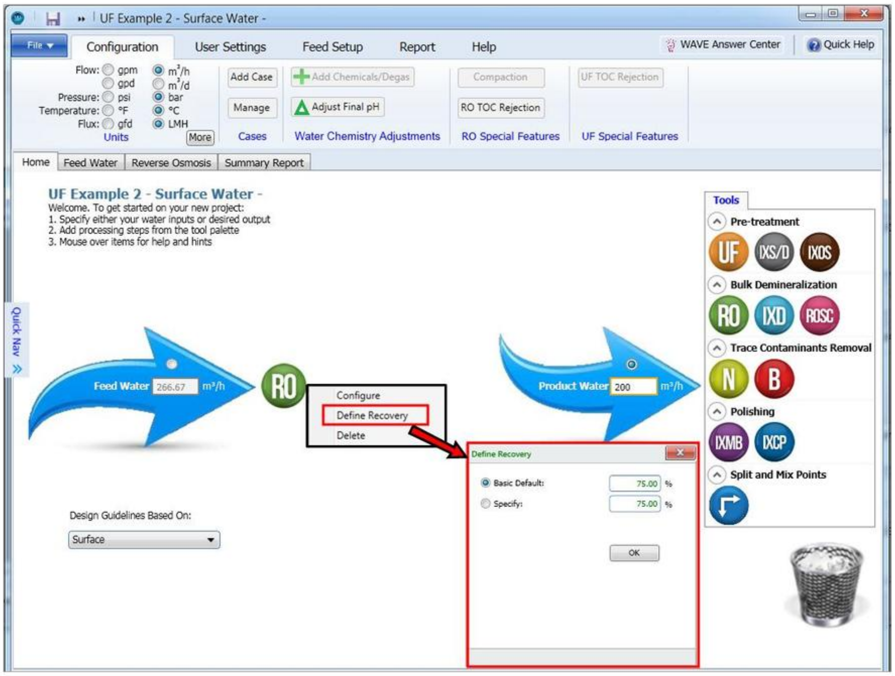


Figure 128. Specification of RO/NF/ROSC system recovery in the Home Tab

4. Click 'OK"

Notes:

- The Basic Default Recovery for an RO/NF/ROSC system is 75% in WAVE
- Once the pass level Recovery is specified, WAVE would calculate the appropriate system Recovery and populate the "Based on RO Config." Field
- Once an RO/NF/ROSC system has been modeled, WAVE would have calculated a System Recovery (possibly based on Feed Pressure). This calculated System recovery would appear in the "Use Last Calculated Value" field.

System Recovery Definition at the Flow Pop-Up Window

b. RO/NF/ROSC System Recovery Definition at the Flow Calculator Pop-up Window

The Recovery for the RO/NF/ROSC system can be defined as follows using WAVE’s (shown in Figure 129):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Click on any entry field in the Flow Specification area (shown in Figure 129. The Flow Calculator Pop-up Window will appear.
3. Specify the Recovery for each pass. The System Recovery would be automatically calculated and displayed in the ‘RO System recovery’ box at the top right corner of the Flow Calculator Pop-up Window.
4. Click “OK”.

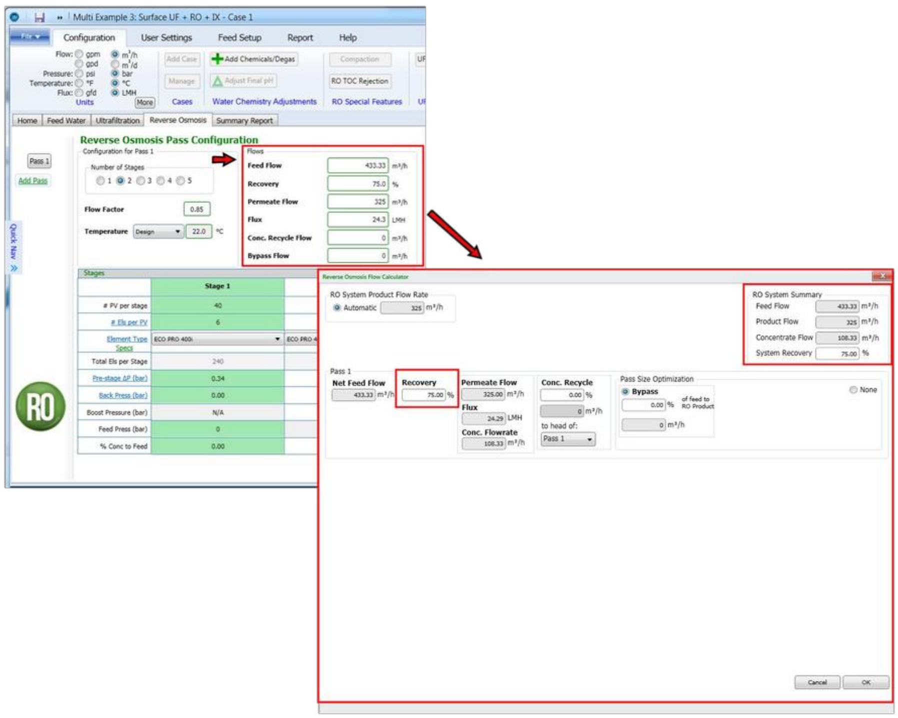


Figure 129. Specification of RO/NF/ROSC system recovery in the Flow Calculator Pop-up Window: accessing the Flow Specification area and defining the Pass Recovery

Notes:

- WAVE assumes a default RO/NF/ROSC System Recovery of 75%. If the Recovery of only one of two passes is updated by the user, WAVE automatically recalculates the Recovery of the other Pass to maintain a System Recovery of 75%.
- WAVE allows the user to manually change the Feed Flow rate value at the Flow Calculator Pop-up Window to see its effect. However, this Feed flow rate would not be used in calculations outside the Flow Calculator and would not be transferred to the Home Tab.

4.1.8 Specifying Flow Patterns (Stage Recirculation, Recycle, Bypass, Split)

Concentrate Recirculation between Stages

WAVE makes it possible to define recirculation of concentrate from downstream elements to the Feed in the same stage. This can be done as shown below (and in Figure 130):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. For each stage and each pass, define the % Stage Recirculation. Note the change in the RO/NF/ROSC Process Flow Diagram.

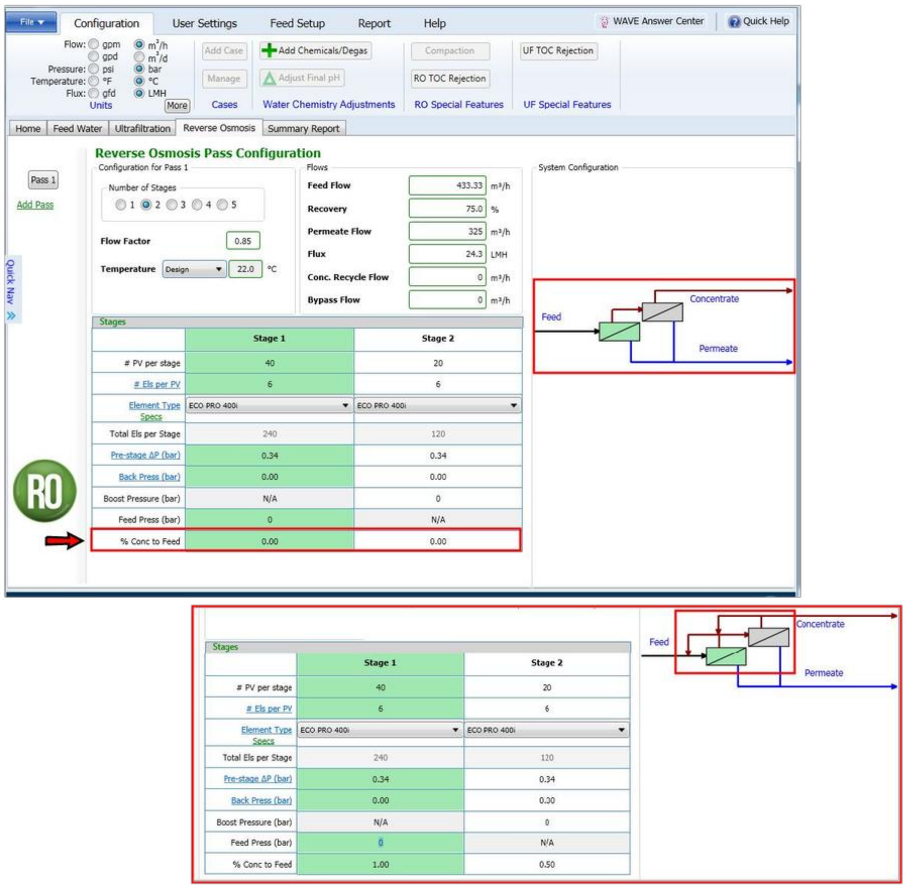


Figure 130. Specification of RO/NF/ROSC system Concentrate Percent Recirculation to Feed in a stage: Before (Upper image) and After (Bottom image)

Note: WAVE allows 0-100% recirculation to the feed for each stage, though when more than 30% is recirculated, an error warning will appear

Concentrate Recycle between the Passes

To help improve System Recovery, a WAVE user may be interested in recirculating the concentrate from a pass to the feed of the same or a different pass. This can be done as follows (and shown in Figure 131):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Click on any entry field in thelow Specification area (shown in Figure 131). The Flow Calculator Pop-up WindoSpecification of RO/NF/ROSC system Concentrate Recycle to Feed: Before (Upper image)

3. Specify the Concentrate Recycle from each Pass and where the Recycle stream would go (Pass 1 or Pass 2). The System Recovery would be automatically calculated and displayed in the 'RO System recovery' box at the top right corner of the Flow Calculator Pop-up Window. However the RO/NF/ROSC Process Flow Diagram would not update until the user clicks "OK".

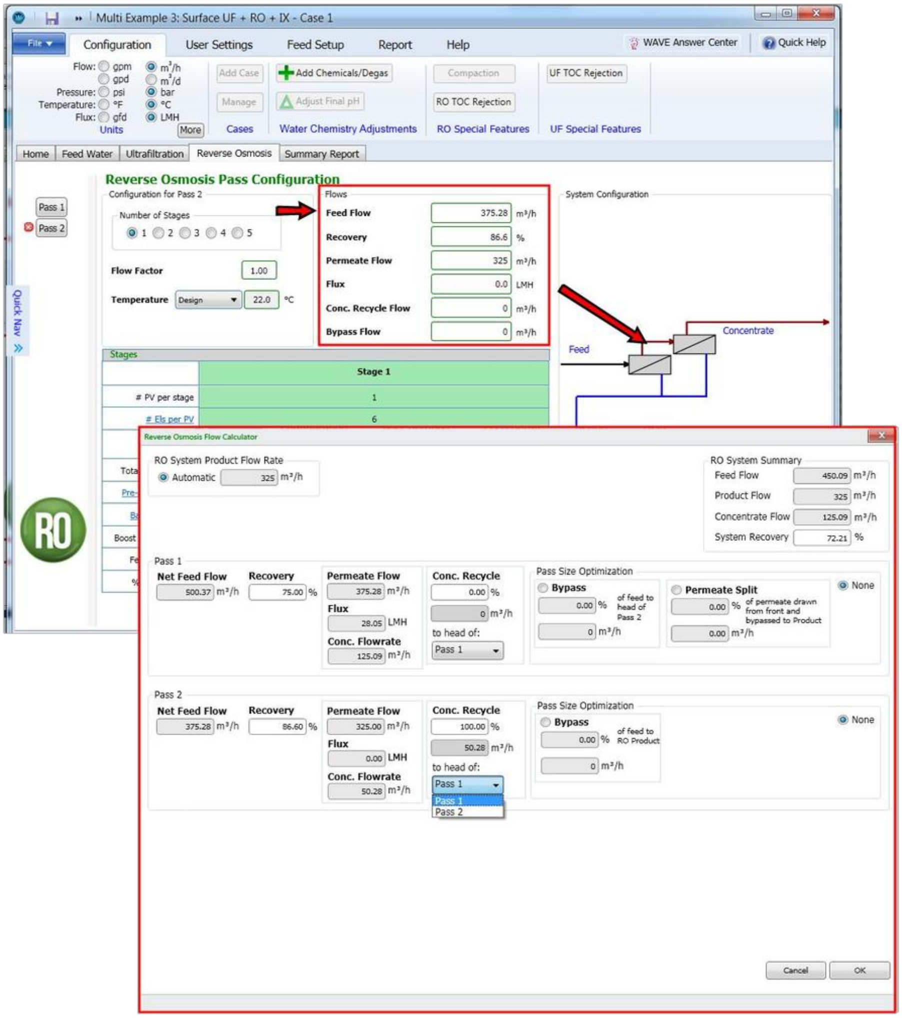


Figure 131. Specification of RO/NF/ROSC system Concentrate Recycle to Feed: Before (Upper image) and After (Bottom image)

4. Click "OK".

Notes:

- WAVE does not allow splitting of the recirculated Concentrate stream to two passes (e.g. 50% of the concentrate from Pass 2 sent to Pass 1 feed, 50% sent to Pass 2 feed)
- WAVE does not allow recirculating the Concentrate from Pass 1 to the feed of Pass 2.
- In WAVE, the user can specify the % of the Concentrate stream to recycle, not the amount. However, WAVE automatically calculates the corresponding Concentrate flow and displays it underneath the % specification fields.

Feed Bypass

To meet permeate quality requirements, it might be necessary to bypass a given Pass and mix the bypassing portion of the Feed with the Permeate from that Pass. WAVE makes this possible using the steps below (as shown in Figure 132 and Figure 133):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Click on any entry field in the Flow Specification area (shown in Figure 21). The Flow Calculator Pop-up Window will appear.
3. Select the “Bypass” radio button for the Pass of interest.
4. Specify the % Bypass (% of total feed to the Pass that bypasses that Pass and becomes part of the Feed of the next Pass or becomes part of the RO/NF/ROSC product). The System Recovery would be automatically calculated and displayed in the ‘RO System recovery’ box at the top right corner of the Flow Calculator Pop-up Window. However the RO/NF/ROSC Process Flow Diagram would not update until the user clicks “OK”.

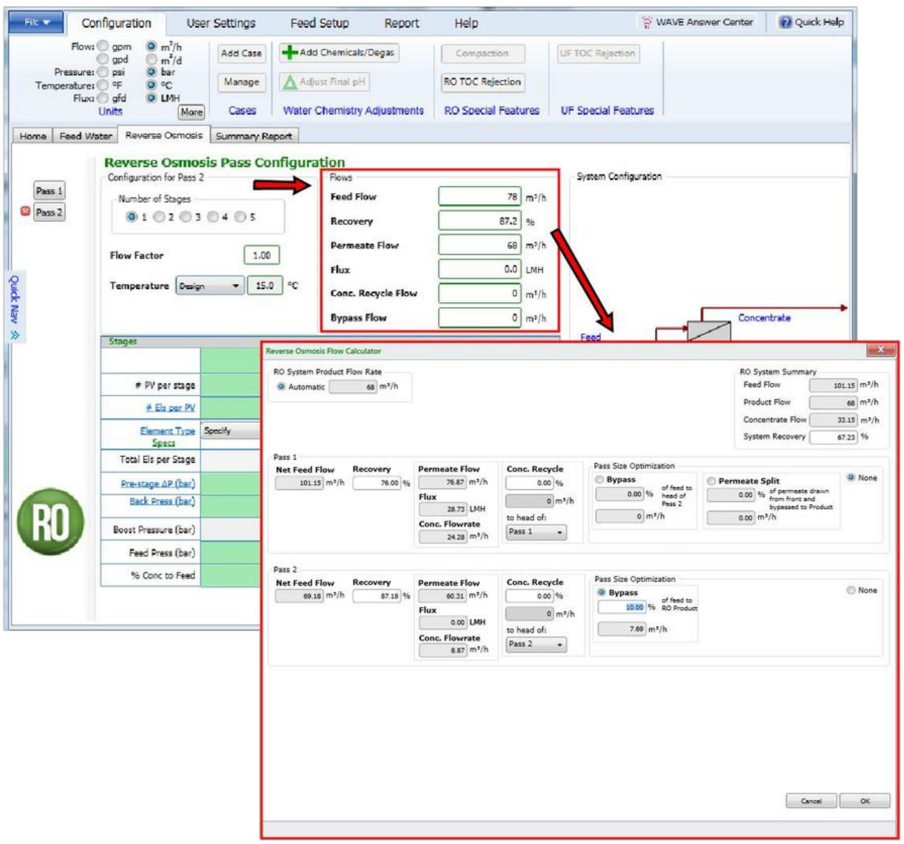


Figure 132. Specification of RO/NF/ROSC system Feed Bypass to Product Before

5. Click “OK”.

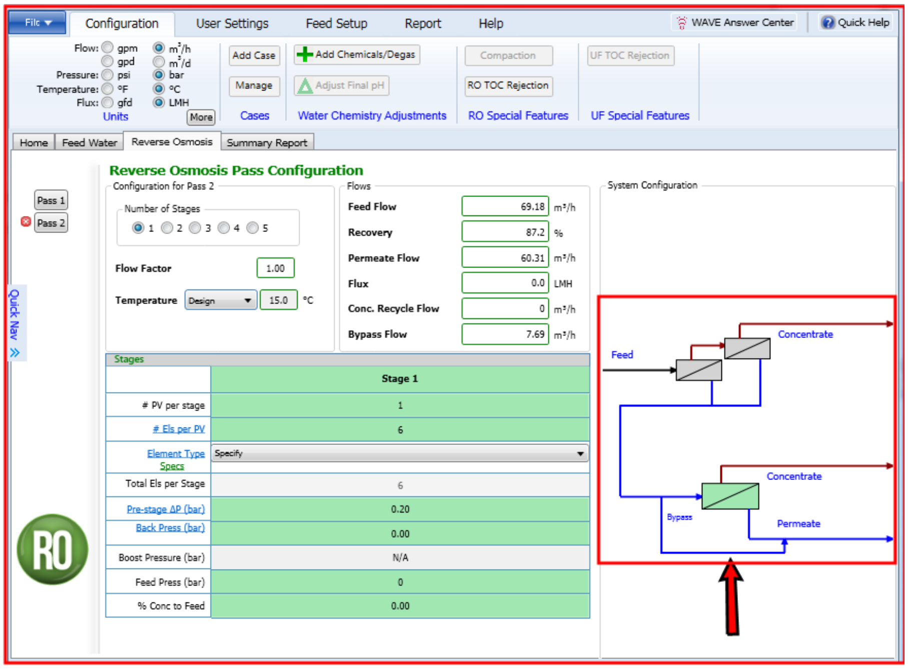


Figure 133. Plant scheme once Feed Bypass is specified for RO/NF/ROSC system

Notes:

- In WAVE, the user can specify the % of the Feed stream to recycle, not the amount. However, WAVE automatically calculates the corresponding bypassing stream flow and displays it underneath the % specification fields.
- In WAVE the user can remove the Bypass stream by clicking on the radio button next to “None” at the top right corner of the Pass Optimization box.
- WAVE always mixes the bypassing Feed stream and the Permeate from the Pass.

Split Permeate

WAVE allows the user to take permeate from intermediate points along the pressure vessel containing the RO/NF/ROSC elements. These intermediate points might be in between elements or sometimes partway through an element. The Permeate upstream of each intermediate point would be ‘split off’ and set directly to product (from that Pass) instead of being mixed with the Permeate streams coming from elements further downstream. The Split Permeate amount can be specified in WAVE as follows (and shown in Figure 134 and Figure 135):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Click on any entry field in the Flow Specification area (shown in Figure 134). The Flow Calculator Pop-up Window will appear.

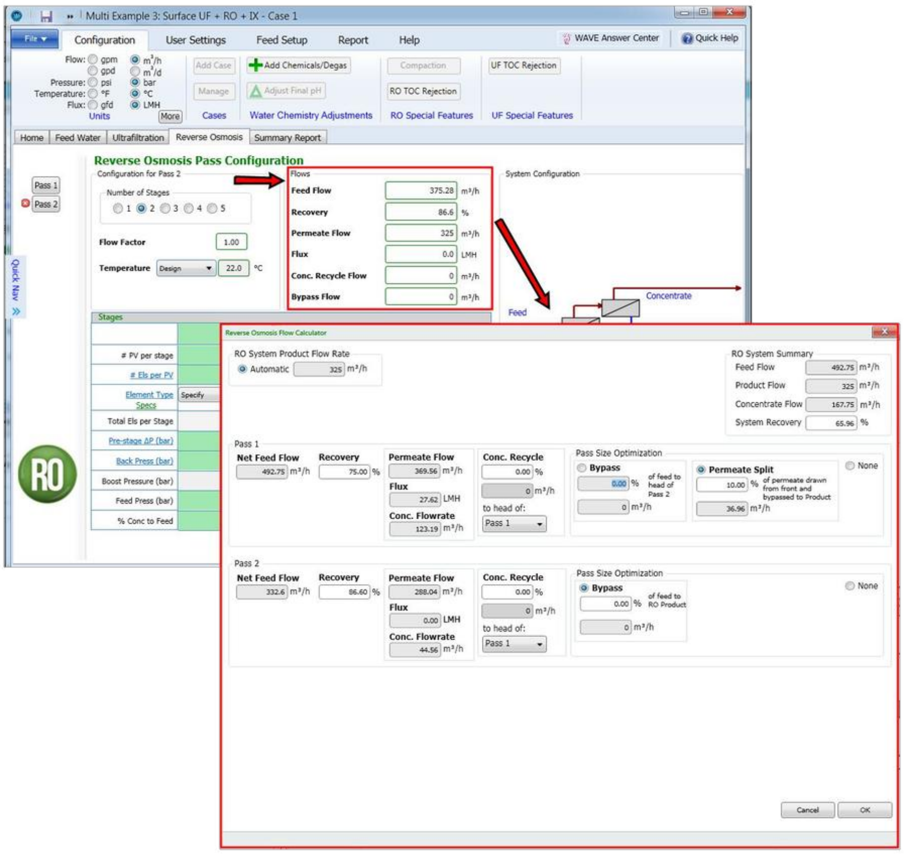


Figure 134. Specification of RO/NF/ROSC system Permeate Split

3. Select the “Split Permeate” radio button for the Pass of interest.
4. Specify the % Permeate Split (% of total permeate from that stage that becomes part of the RO/NF/ROSC product). The System Recovery would be automatically calculated and displayed in the ‘RO System Recovery’ box at the top right corner of the Flow Calculator Pop-up Window. However the

5. RO/NF/ROSC Process Flow Diagram would not update until the user clicks "OK".

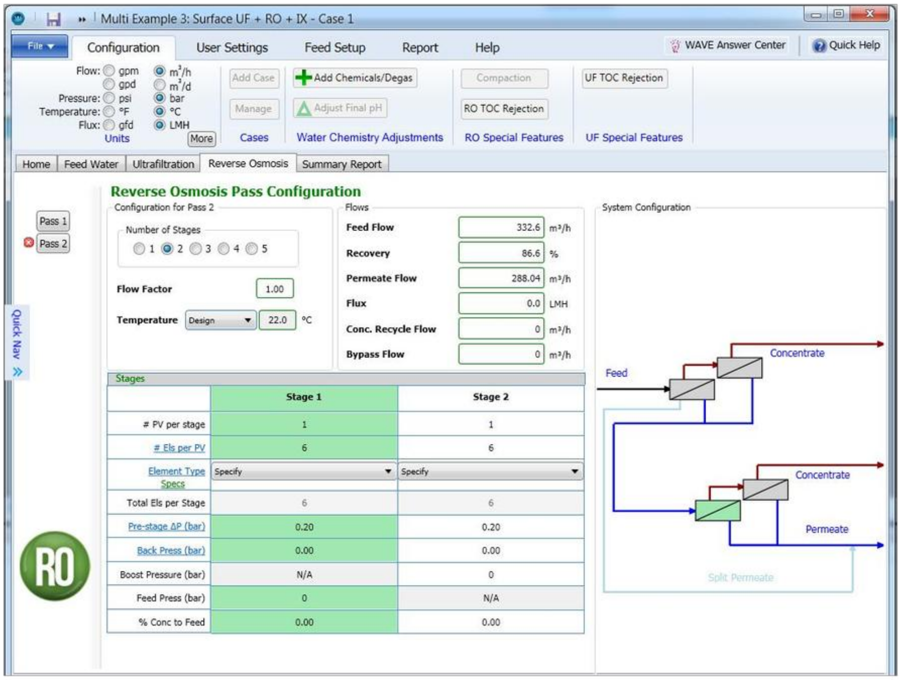


Figure 135. Plant scheme once Permeate Split is specified for RO/NF/ROSC system

6. Click "OK".

Notes:

- In WAVE, the Split Permeate stream is defined at the Pass level.
- WAVE requires at least two passes for Split Permeate to work.
- In WAVE, the user can specify the % of the Permeate split off to product, not the amount. However, WAVE automatically calculates the corresponding permeate split stream flow and displays it underneath the % specification field.
- In the RO/NF/ROSC Process Flow Diagram, the Split Permeate is always shown to emerge from the 1st stage in WAVE.
- In WAVE the user can remove the Split Permeate by clicking on the radio button next to "None" at the top right corner of the Pass Optimization box.

4.1.9 Specifying pH Adjustment/Degasification and Calculating the Risk of Scaling

pH Adjustment of the Feed to Each Pass

WAVE provides the possibility for increasing or decreasing the pH of a Feed to a given Pass as shown below (and in Figure 136):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Select the Pass of interest (Pass 1 or Pass 2 in WAVE).

3. Click on the “Add Chemicals/Degas” button. The Chemical Adjustment Popup Window will appear. This Window includes options for adjusting pH, degasification, addition of Antiscalants/SMBS (only the 1st Pass), specifying the process temperature and Pass recovery. This Window also includes a Table with the Feed composition (before adjustment) and the Concentrate composition calculated by WAVE.
4. Click on either of the “pH” buttons. The gray dots on the buttons would turn green. The Table in the Chemical Adjustment Popup Window would now include a column named “After pH”
5. Click on the entry fields for either pH or S&DI (Stiff & Davis Index) and specify the desired pH or S&DI value. WAVE would populate the “After pH” columns in the Table in the Chemical Adjustment Popup Window. This would be reflected in the RO/NF/ROSC Process Flow Diagram after the user clicks “OK” (arrows in the feed streams to each pass with named chemicals).
6. Choose the appropriate chemical from dropdown list. This list would be different for increasing pH vs. decreasing pH.
7. Click “OK”.

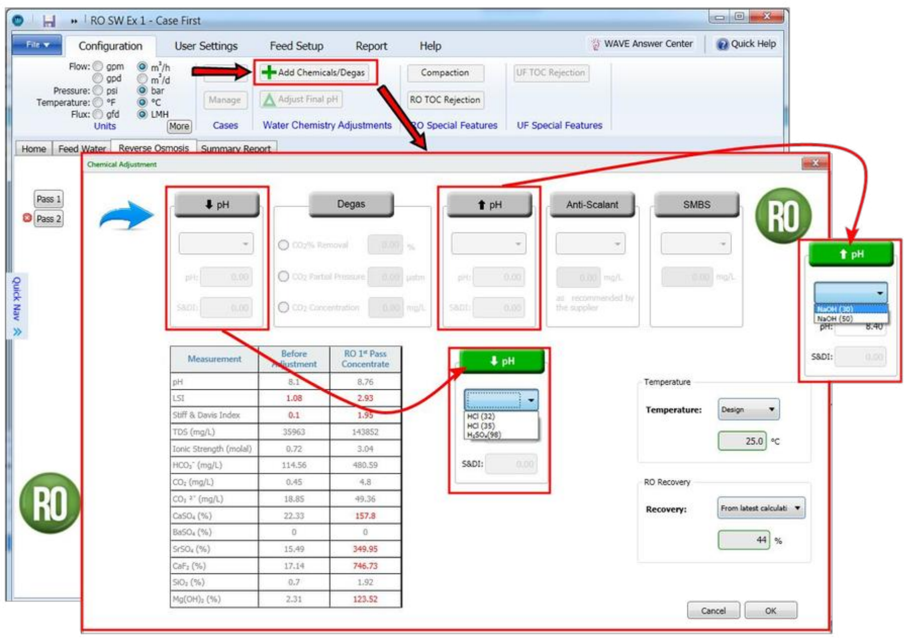


Figure 136. Specification of RO/NF/ROSC System Pass Feed pH Adjustment

Notes:

- In WAVE, pH adjustment can be deactivated by choosing either of “pH” buttons a second time. The green dots would turn gray.
- In WAVE, pH specifications are limited to between 0 and 14.
- The list of chemicals used for pH adjustment is defined by the user as described in Section 1.
- WAVE allows addition of Antiscalants and SMBS only in the 1st Pass and does not allow pH adjustment between stages
- WAVE does not prevent the simultaneous selection of “pH” without an intermediate degasification step. Thus the user is urged to review the pH adjustment selections carefully.

pH Adjustment of the Final Product

This involves adjustment of the pH of the Permeate from the RO/NF/ROSC system. This feature, as described in Section1, is available to all three technologies (UF, RO/NF/ROSC/ IX). The steps are as follows (Figure 137):

1. Click on the **Home** Tab if you are in a different Tab or Window.
2. Click on “Adjust Final pH”.
3. Click on the “pH” button.
4. Specify the pH of interest then click “OK”.

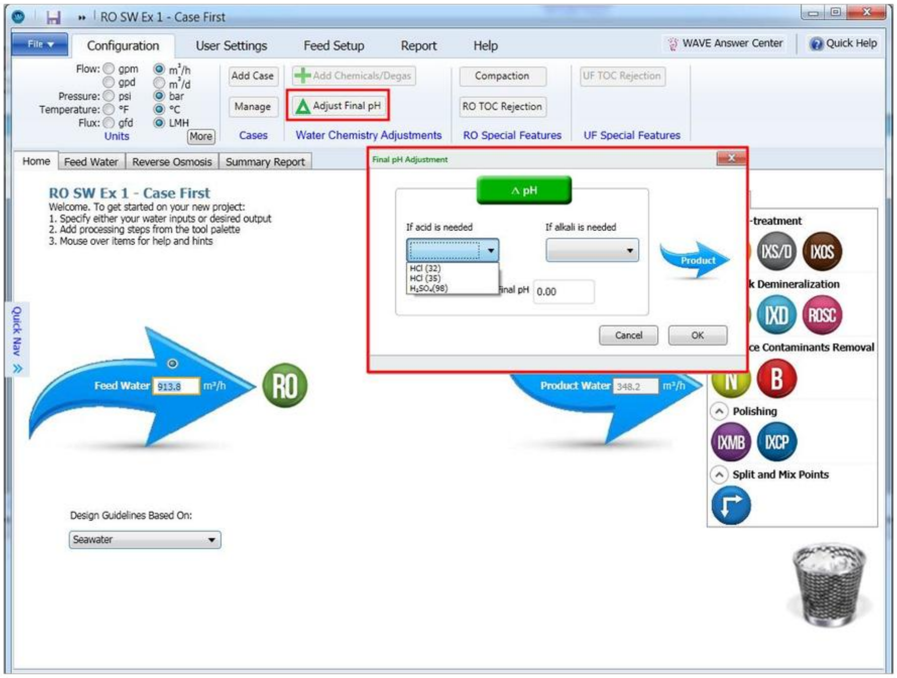


Figure 137. Specification of RO/NF/ROSC System Pass Feed pH Adjustment

Notes:

- In WAVE, pH adjustment can be deactivated by choosing “pH” button a second time. The green dots would turn gray.
- In WAVE, pH specifications are limited to between 0 and 14.
- The list of chemicals used for pH adjustment is defined by the user as described in Section 1.
- WAVE allows the simultaneous selection of “pH” without an intermediate degasification step. Thus the user is urged to review the pH adjustment selections carefully.

Degasification

Carbon dioxide removal from RO/NF/ROSC feed streams can be modeled in WAVE. This process is usually accompanied by pH adjustment. The steps below can be used (as shown in Figure 138):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.
2. Select the Pass of interest (Pass 1 or Pass 2 in WAVE).

3. Click on the "Add Chemicals/Degas" button. The Chemical Adjustment Popup Window will appear. This Window includes options for adjusting pH, degasification, addition of Antiscalants/SMBS (only the 1st Pass), specifying the process temperature and Pass recovery. This Window also includes a Table with the Feed composition (before adjustment) and the Concentrate composition calculated by WAVE.

4. Click on the "Degas" button, which should turn green. The Table in the Chemical Adjustment Popup Window would now include a column named "After Degas". This would be reflected in the RO/NF/ROSC Process Flow Diagram after the user clicks "OK" (degasification symbol).

5. Click on one of the radio buttons next to entry fields for either" CO2 % Removal", "CO2 Partial Pressure" or "CO2 Concentration (mg/L)". WAVE would populate a grey box on the Ro diagram in the RO screen.

6. Click "OK".

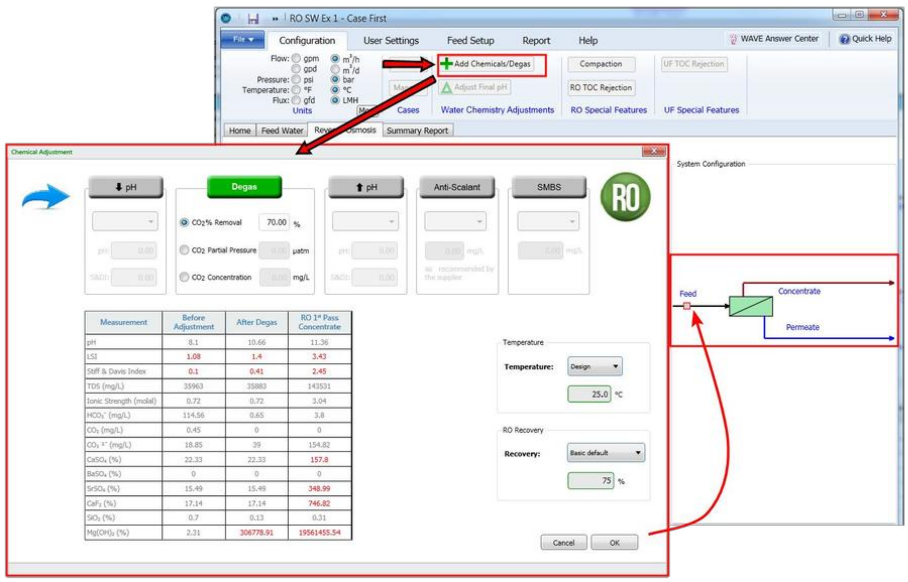


Figure 138. Specification of RO/NF/ROSC System Degasification Specification: Choosing "Add Chemicals/Degas"; Choosing Degasification; Specifying CO2 removal and completion

WAVE would populate a grey box with red border on the RO diagram in the RO screen.

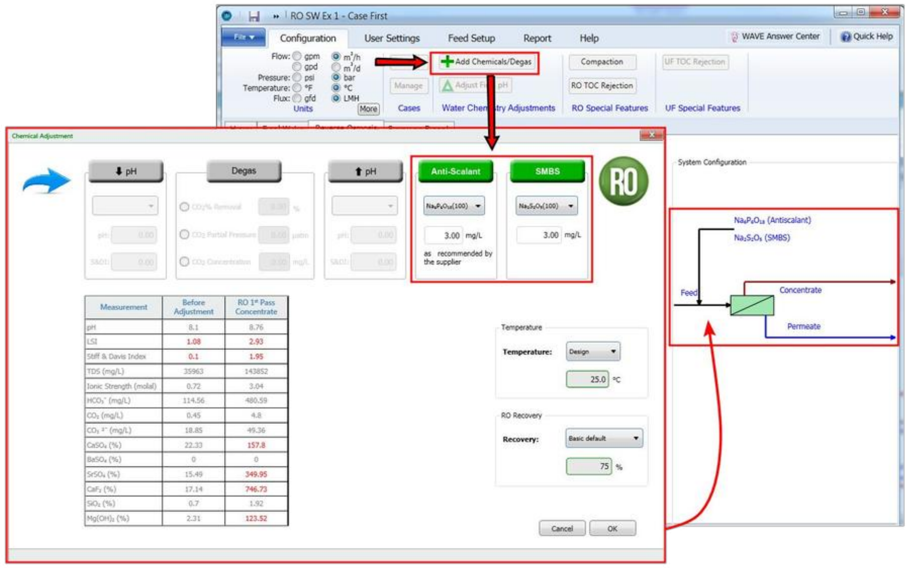
Antiscalant and SMBS Addition

WAVE provides the possibility for adding Antiscalants or SMBS (Sodium Meta-BiSulfite) in a similar manner to pH adjustment as shown below (and in Figure 139):

1. Click on the Reverse Osmosis Tab if you are in a different Tab or Window.

2. Select the Pass of interest (Pass 1 in WAVE).

3. Click on the “Add Chemicals/Degas” button. The Chemical Adjustment Popup Window will appear. This Window includes options for adjusting pH, degasification, addition of Antiscalants/SMBS (only the 1st Pass), specifying the process temperature and Pass recovery. This Window also includes a Table with the Feed composition (before adjustment) and the Concentrate composition calculated by WAVE.



4. Click on the “Anti-Scalant” and/or “SMBS” buttons. The gray dots on the buttons would turn green.

5. Click on the entry fields for Anti-Scalant and/or SMBS and specify the desired composition in the Feed in mg/L. This would be reflected in the RO/NF/ROSC Process Flow Diagram after the user clicks

6. “OK” (arrows in the feed streams to each pass with named chemicals).

7. Choose the appropriate chemical from dropdown list for Antiscalant and SMBS and click “OK”.

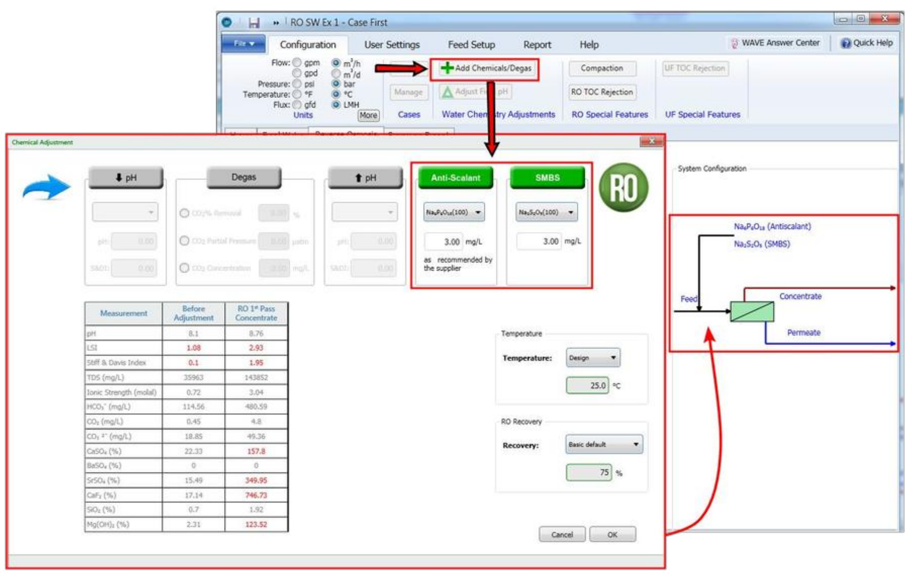


Figure 139. Specification of RO/NF/ROSC System Antiscalant and SMBS Specification (a) Choosing “Add Chemicals/Degas” (b) Choosing Antiscalant/ SMBS (c) Specifying amounts and completion

Notes:

- WAVE does not consider the effect of the addition of Antiscalants and/or SMBS on the Feed or Concentrate composition.
- The addition of Antiscalants and/or SMBS can be deactivated by choosing the "Anti-Scalant" and/or "SMBS" buttons a second time. The green dots would turn gray.
- The list of chemicals for Antiscalants in defined by the user as shown in Section 1. Antiscalant manufacturers should always be consulted for the appropriate dosage of antiscalant.
- WAVE allows addition of Antiscalants and SMBS only in the 1st Pass and does not allow chemical addition between stages.

Calculation of Scaling Risk

The Chemical Adjustment Popup Window in WAVE provides a convenient way to calculate the risk of scaling. Within the Chemical Adjustment Popup Window, the user can modify pH, temperature and Pass Recovery.

To calculate scaling risk at different Recovery values, one must follow these steps:

1. Click on the dropdown arrow next to the Recovery field.
2. Select the appropriate Recovery value:
    a. Basic default (75%),
    b. One based on the given RO/NF/ROSC configuration,
    c. One based on the previous WAVE run
    d. Another values (using the 'Specify') option.
3. The composition table would be updated automatically.

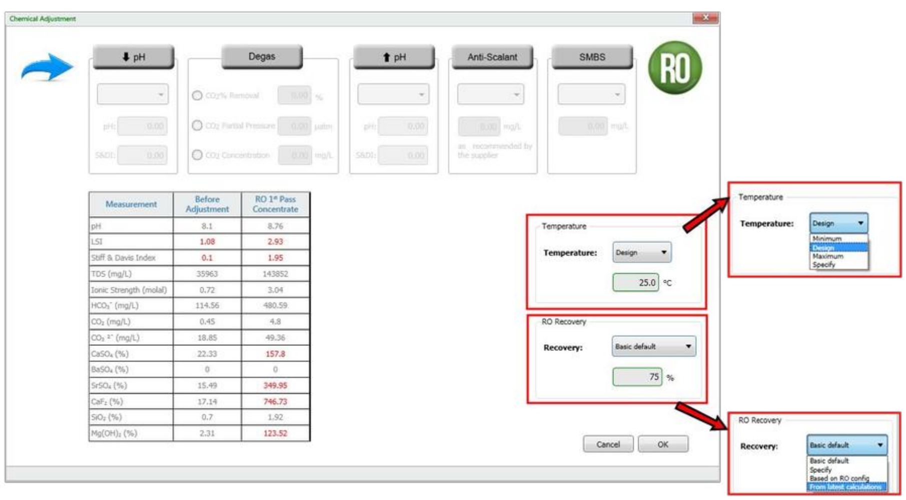


Figure 140. Scaling risk calculation using: Different recovery values

To calculate scaling risk at different temperature values, one must follow these steps:

1. Click on the dropdown arrow next to the temperature field.
2. Select the appropriate temperature value:
    a. Design temperature
    b. Maximum temperature
    c. Minimum temperature
    d. Another values (using the 'Specify') option.
3. The composition table would be updated automatically.

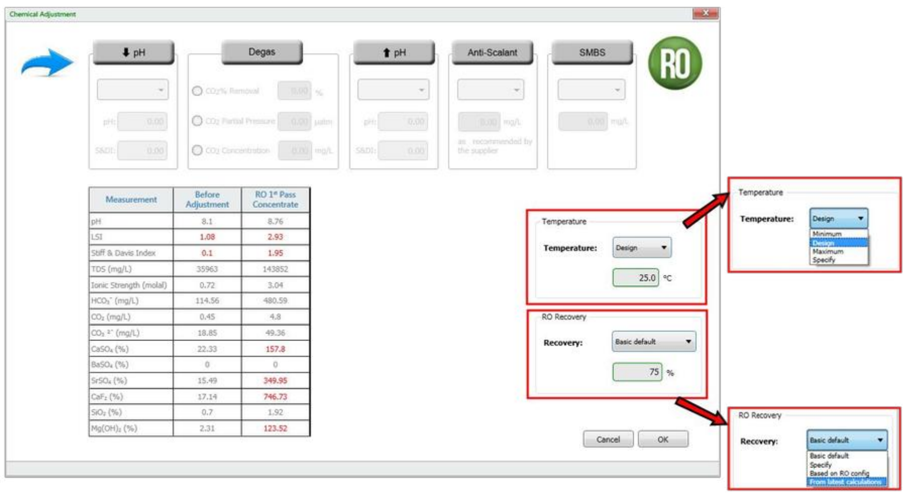


Figure 141. Scaling risk calculation using: Different recovery values and Different temperatures

Notes:

- Scaling risk in the Chemical Adjustment Popup Window is calculated in terms of the Langelier Saturation Index (LSI), Stiff & Davis Index (S&DI) as well as % saturation for some salts ($CaSO_4$, $BaSO_4$, $SrSO_4$, CaF_2), $Mg(OH)_2$ and SiO_2 .
- WAVE does not provide a mechanism to estimate the efficacy of antiscalants. Thus the user is advised to consult with an antiscalant manufacturer.
- Even though the user can estimate the scaling risk using different recovery and temperature values, neither the recovery nor the temperature values are transferred outside of the Chemical Adjustment Popup Window. If the user discovers a combination of temperature and recovery that would minimize scaling risk, he/she would have to copy over the values into the Home and Reverse Osmosis Tabs and perform the design again.

4.2 REVERSE OSMOSIS - FINAL CALCULATION AND REPORT GENERATION

Once the system design inputs are available in WAVE, WAVE can be run to model the system. The details of the following actions that can be performed to generate, modify and handle the reports are described below:

4.2.1 Generation and Understanding of Summary report

Once all the required inputs are in place in the Ultrafiltration Tab, the RO system can be simulated by clicking on the "Summary Report" Tab to generate the Summary Report and the "Detailed Report" button as shown in Figure 142.

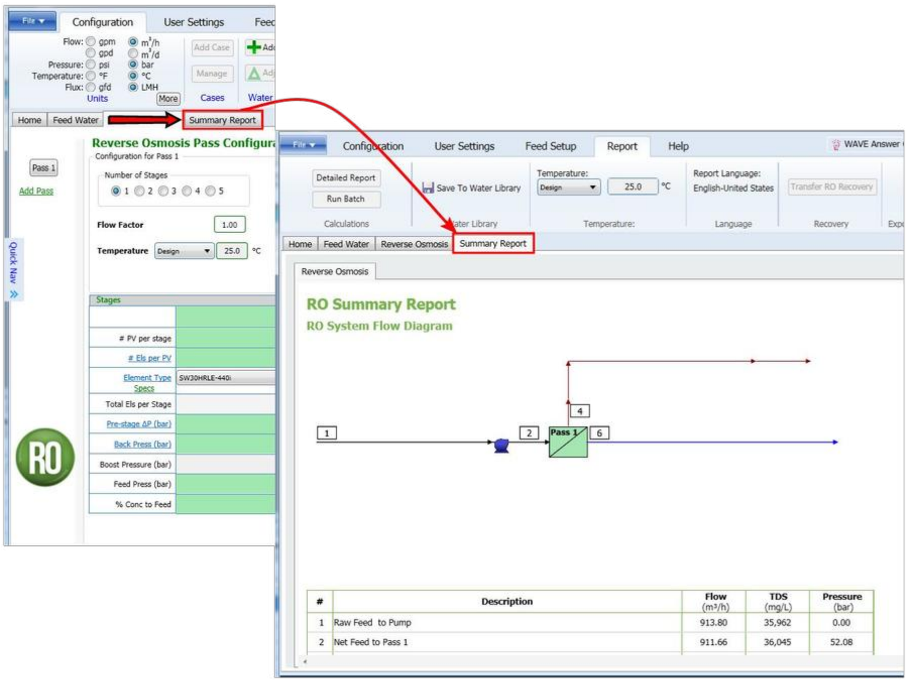
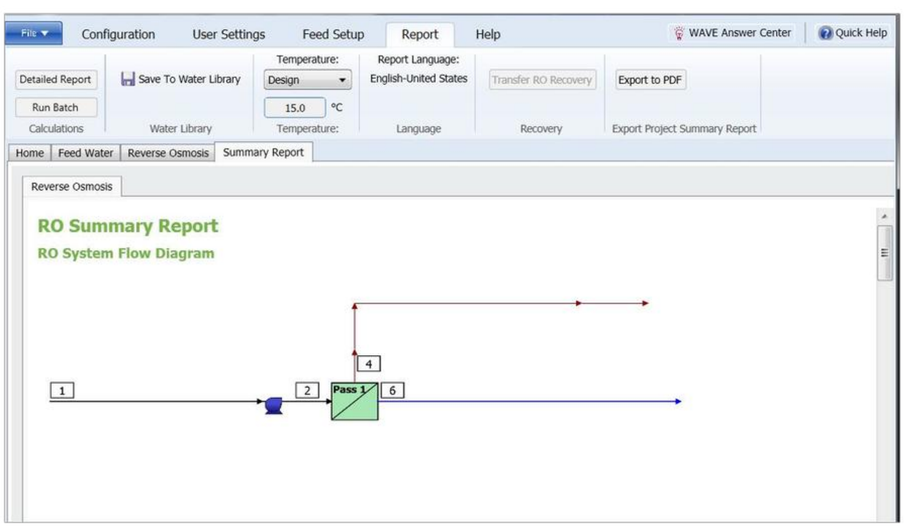


Figure 142. WAVE simulation and report generation for UF

In the Summary report the RO system diagram and some key output are described as shown below.

The RO system is described in a Pass level Process Flow diagram as shown below. The streams are numbered for clarity. This would look different from the RO/NF/ROSC Process Flow Diagram in the Reverse Osmosis Tab (which describes the process at the Stage level).



These tables provide an overview of the RO/NF/ROSC system.

#	Description	Flow (m^3/h)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to Pump	89.47	180	0.00
2	Net Feed to Pass 1	89.45	180	7.43
4	Total Concentrate from Pass 1	21.47	745	5.35
6	Total Permeate from Pass 1	68.00	1.01	0.00

RO System Overview

Total # of Trains 1	Online = 1	Standby = 0	RO Recovery 76.00 %
System Flow Rate (m^3/h)	Net Feed = 89.47	Net Product = 68.00	

Pass	Pass 1
Stream Name	Stream 1
Water Type	Surface Water (SDI < 5)
Number of Elements	72
Total Active Area (m^2)	2675.61

Feed Flow per Pass (m^3/h)	89.45
Feed TDS (mg/L)	180
Feed Pressure (bar)	7.43
Flow Factor	1.00
Permeate Flow per Pass (m^3/h)	68.00
Pass Average flux (LMH)	25.4
Permeate TDS (mg/L)	1.01
Pass Recovery	76.0 %
Average NDP (bar)	6.03
Specific Energy (kWh/m^3)	0.34
Temperature (°C)	15.0
pH	7.20
Chemical Dose	
RO System Recovery	76.0 %
Net RO System Recovery	76.0%

There are several components to note from the Overview Table

1. The Chemicals added to adjust pH and prevent scaling
2. In the case of more complicated designs (e.g. involving permeate split or feed bypass), there would be asterisks on the Stage and Pass respectively that mark where the split or bypass happened. The user is then urged to look at the RO system diagram and flow tables for clarification.

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (m^3/h)	Recirc Flow (m^3/h)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m^3/h)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m^3/h)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1	ECO PRO 400	8	6	89.45	0.00	7.09	0.00	41.66	6.30	0.79	47.80	26.8	0.00	0.93
2	ECO PRO 400	4	6	41.66	0.00	6.10	0.00	21.47	5.35	0.75	20.20	22.6	0.00	1.20

The RO Water Quality Table provides a convenient summary of the process by describing the feed and permeate compositions for all passes and permeate split streams, as well as a blended final product stream.

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)				
	Feed	Conc.	Permeate	
		Stage1	Stage1	Total
NH_4^+	0.00	0.00	0.00	0.00
K^+	408.41	728.40	3.07	3.07
Na^+	11,038	19,695	71.94	71.94
Mg^{+2}	1,314	2,349	1.98	1.98
Ca^{+2}	421.69	754.09	0.63	0.63
Sr^{+2}	8.14	14.56	0.01	0.01
Ba^{+2}	0.00	0.00	0.00	0.00
CO_3^{-2}	18.86	35.68	0.00	0.00
HCO_3^-	114.55	201.37	1.05	1.05
NO_3^-	0.00	0.00	0.00	0.00
Cl^-	19,835	35,399	118.78	118.78
F^-	1.33	2.37	0.01	0.01
SO_4^{-2}	2,776	4,965	1.65	1.65
Br^-	0.00	0.00	0.00	0.00
CO_2	0.45	0.99	0.53	0.53
SiO_2	1.00	1.79	0.01	0.01
Boron	4.59	7.47	0.94	0.94
TDS	35,962	64,190	205	205
pH	8.10	8.05	6.45	6.45

WAVE provides Design warnings as well as potential solutions. The Pass, Stage and Element at which the warning is triggered is identified:

RO Design Warnings

Design Warning	Limit	Value	Pass	Stage	Element	Product
Element Recovery > Maximum Limit (%)	15.00	15.67	1	1	6	ECO PRO 400

RO Flow Table (Element Level) - Pass 1

Stage	Element	Recovery (%)	Feed Flow (m^3/h)	Feed Press (bar)	Feed TDS (mg/L)	Conc Flow (m^3/h)	Perm Flow (m^3/h)	Perm TDS (mg/L)
1	1	9.33	11.18	7.09	180	10.14	1.04	0.90
1	2	10.03	10.14	6.90	198	9.12	1.02	0.90
1	3	10.92	9.12	6.74	220	8.13	1.00	0.90
1	4	12.07	8.13	6.60	247	7.15	0.98	0.90
1	5	13.59	7.15	6.48	281	6.18	0.97	0.90
1	6	15.67	6.18	6.38	325	5.21	0.97	1.00
2	1	8.59	10.42	6.10	385	9.52	0.89	1.00
2	2	9.12	9.52	5.93	421	8.65	0.87	1.00
2	3	9.77	8.65	5.78	463	7.81	0.85	1.10
2	4	10.59	7.81	5.64	513	6.98	0.83	1.20
2	5	11.64	6.98	5.53	573	6.17	0.81	1.30
2	6	13.00	6.17	5.43	649	5.37	0.80	1.50

The scaling risk is summarized in the table below. In the RO Scaling Table, WAVE would flag % saturation values > 100, LSI >0 and S&DI >0 by changing the color of the number to red. However, only one of LSI or S&DI would be displayed in the top panel. The display is based on the concentrate characteristics.

RO Solubility Warnings

Warning	Pass No
Langelier Saturation Index > 0	1
Anti-scalants may be required. Consult your anti-scalant manufacturer for dosing and maximum allowable system recovery.	1

RO Chemical Adjustments

	Pass 1 Feed	RO 1st Pass Conc	Pass 2 Feed	RO 2nd Pass Conc
pH	7.20	7.62	5.24	5.67
Langelier Saturation Index	-1.42	-0.12	-7.93	-6.26
Stiff & Davis Stability Index	-0.31	0.61	-4.79	-3.63
TDS (mg/l)	149	440	0.9	3.2
Ionic Strength (molal)	0.00	0.01	0.00	0.00
HCO_3^- (mg/L)	74.82	219.96	0.68	2.00
CO_2 (mg/l)	8.43	8.73	8.27	8.79
CO_3^{-2} (mg/L)	0.06	0.58	0.00	0.00
$CaSO_4$ (% saturation)	0.11	0.88	0.00	0.00
$BaSO_4$ (% saturation)	0.00	0.00	0.00	0.00
$SrSO_4$ (% saturation)	0.00	0.00	0.00	0.00
CaF_2 (% saturation)	0.00	0.00	0.00	0.00
SiO_2 (% saturation)	9.09	26.84	0.01	0.07
$Mg(OH)_2$ (% saturation)	0.00	0.00	0.00	0.00

Standard Mode without Compaction

Once all the required inputs in the Reverse Osmosis Tab, the Flow Calculator Pop-up Window and the Chemical Adjustment Popup Window are in place, the RO/NF/ROSC system can be simulated using the following step (Figure 143):

1. Click on the "Summary Report" tab. The simulation results would be generated in a Summary report.
2. For Detailed Report, click on ¨Detailed Report¨tab.

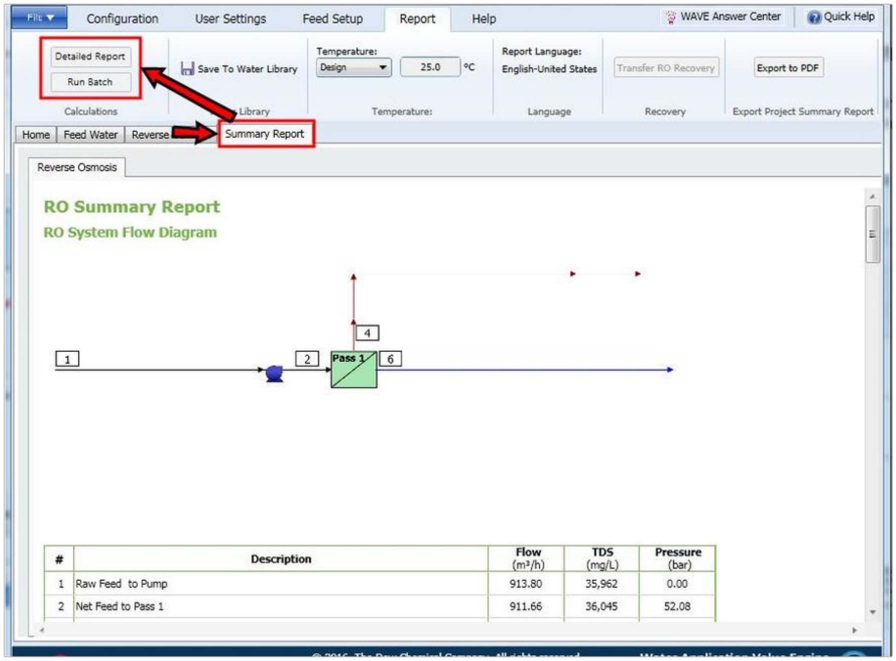


Figure 143. WAVE simulation and report generation

Standard Mode with Compaction

RO/NF membrane compact when feed pressure is applied on them; however there is little lasting impact on performance estimated by default in WAVE. It is possible to incorporate the possibility of lasting impact on membrane performance by the combination of increased temperature and operation at high pressure in WAVE as follows (and in Figure 144):

1. Click on the Reverse Osmosis Tab.
2. Click on the "Compaction" button. The Compaction Feature Popup Window will appear.
3. Click on the checkbox next to "Account for flux loss at high temperature"
4. Set the highest temperature the system is exposed to
5. Click "Save"

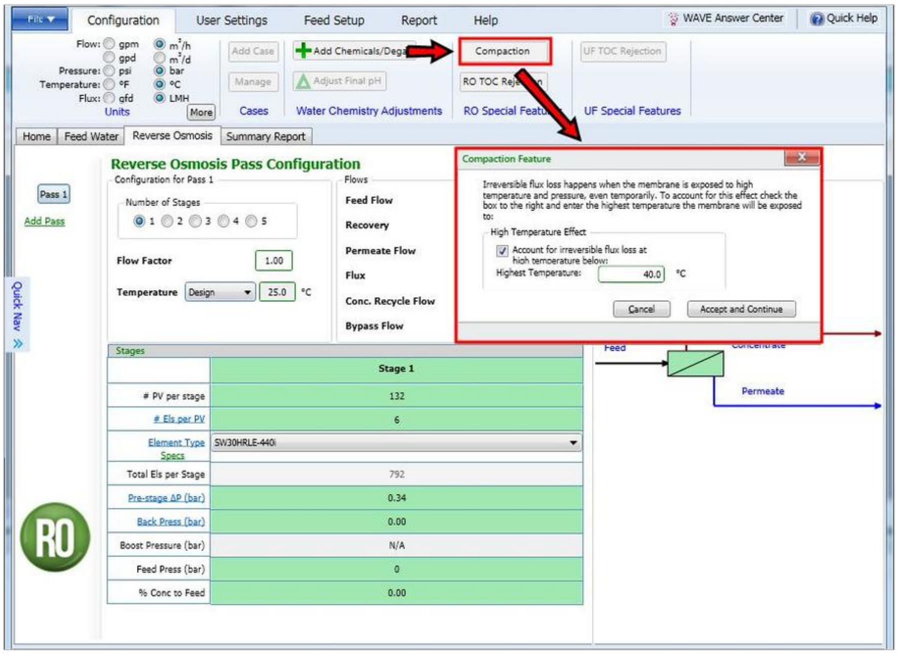


Figure 144. WAVE report regeneration and additional simulation by including compaction: Selecting Compaction and Setting the highest temperature and enabling the compaction calculations

Notes:

- The highest temperature entry in the Compaction Feature Popup Window can be different from the Maximum temperature set in the Feed Water Tab but it has to be between the Minimum and Maximum temperatures set in the Feed Water Tab.
- The Compaction button would be active only for seawater feed.
- There is a second way of modeling compaction; using the Batch Processing mode as described next.

Batch Mode

In designing RO/NF/ROSC systems, there is often interest in understanding the behavior of the system at multiple design conditions. Rather than changing the parameters one at a time, WAVE provides the possibility of simulating the system at multiple values of select parameters: Temperature and Flow Factor. WAVE is run in Batch mode as described below.

1. Create a case and generate the Summary Report.
2. Click on the "Run Batch" button. The Batch Processing Popup Window will appear (Figure 145).

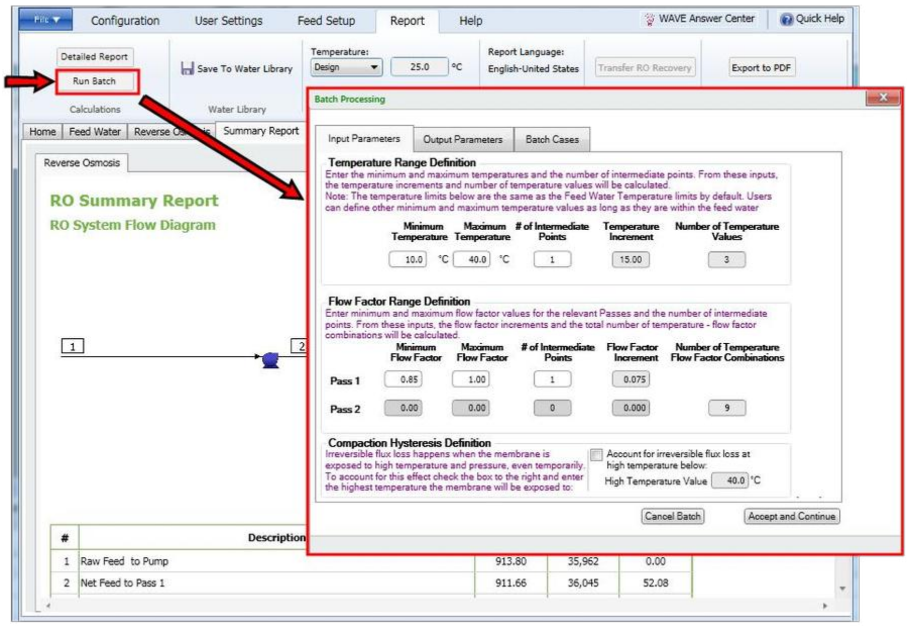


Figure 145. Running WAVE in Batch Mode: Activating Batch Mode

3. Update the Minimum and Maximum temperature values if needed.
4. Update the number of intermediate points of interest between the Minimum and Maximum temperature values. WAVE would automatically calculate the temperature step size.
5. Update the Startup and Long term Flow Factor values for the relevant Pass. By default, the values are 1 and 0.85 respectively for all passes.
6. If compaction needs to be considered, check the box next to "Account for flux loss at high temperature" and specify the highest temperature the membrane is exposed to.

7. Click on the Output Parameters Tab in the Batch Processing Popup Window and confirm that all the variables of interest are going to be displayed Figure 146).

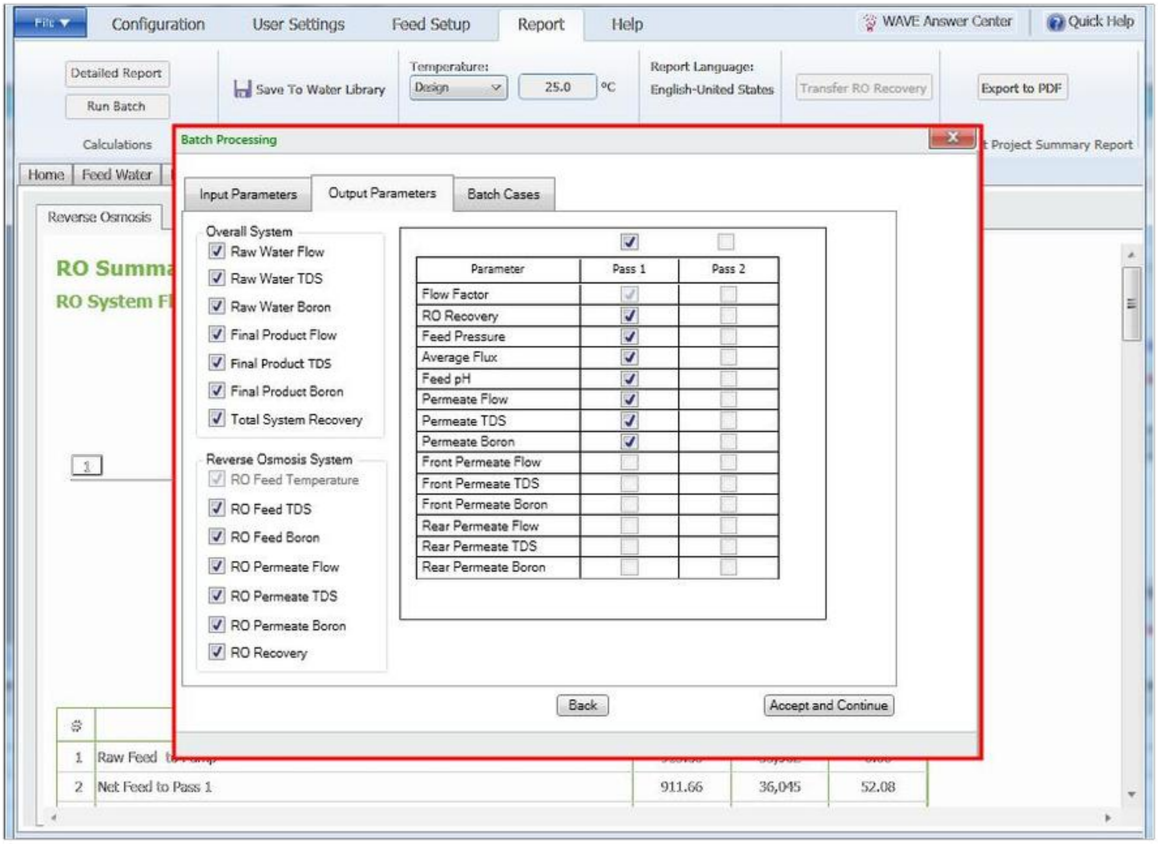


Figure 146. Running WAVE in Batch Mode: Confirming desired output of Batch run

8. Click on the Batch Cases Tab in the Batch Processing Popup Window and select which combinations of Temperature and Flow Factor are to be converted to Cases. WAVE would generate a table with all the possible combinations of the given Flow Factors and the Temperature values (including the minimum, maximum and all intermediate values) and the corresponding results (Figure 147).

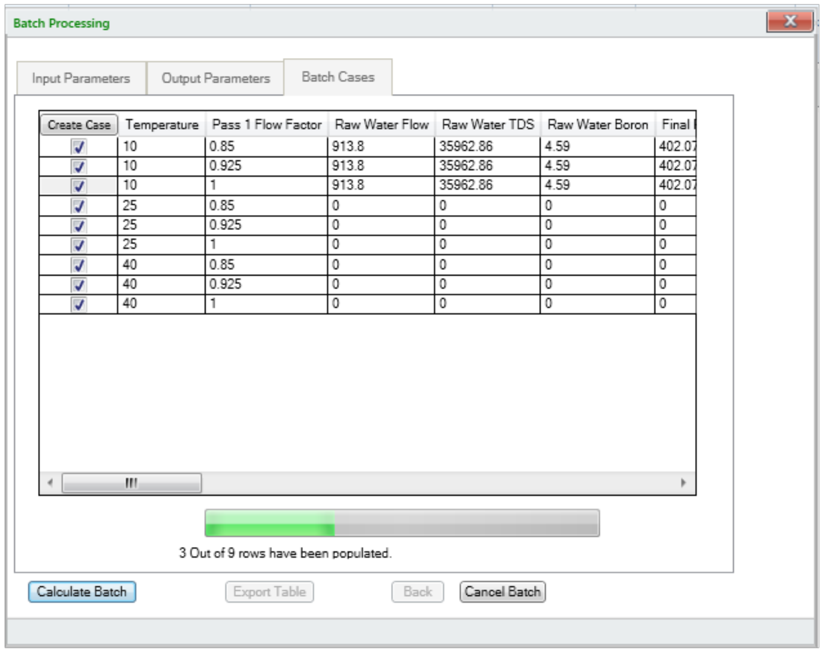
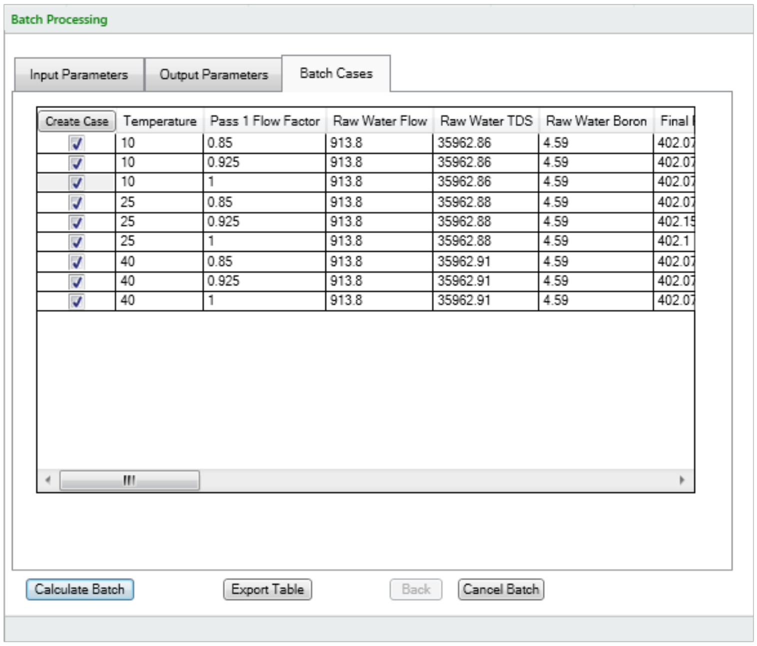


Figure 147. Running WAVE in Batch Mode: Selection of which combinations to test and implementing the batch run

9. To generate Cases, click on the ‘Create Case” button (Figure 147).

10. Click “Calculate Batch”. WAVE would start to populate the empty fields (selected in the Output Parameters tab) with calculation results (Figure 148).



Create Case	Temperature	Pass 1 Flow Factor	Raw Water Flow	Raw Water TDS	Raw Water Boron	Final l
✓	10	0.85	913.8	35962.86	4.59	402.07
✓	10	0.925	913.8	35962.86	4.59	402.07
✓	10	1	913.8	35962.86	4.59	402.07
✓	25	0.85	913.8	35962.88	4.59	402.07
✓	25	0.925	913.8	35962.88	4.59	402.15
✓	25	1	913.8	35962.88	4.59	402.1
✓	40	0.85	913.8	35962.91	4.59	402.07
✓	40	0.925	913.8	35962.91	4.59	402.07
✓	40	1	913.8	35962.91	4.59	402.07

Figure 148. Running WAVE in Batch Mode:Final output

Note: By default the temperature entries in the Input Parameters tab of the Batch Processing Window are taken from the entries in the Feed Water Tab but they can be over-ridden for Batch calculations.

4.2.2 Generating and Understanding the RO Detailed Report

RO Detailed Report can be generated as shown on Figure 149.

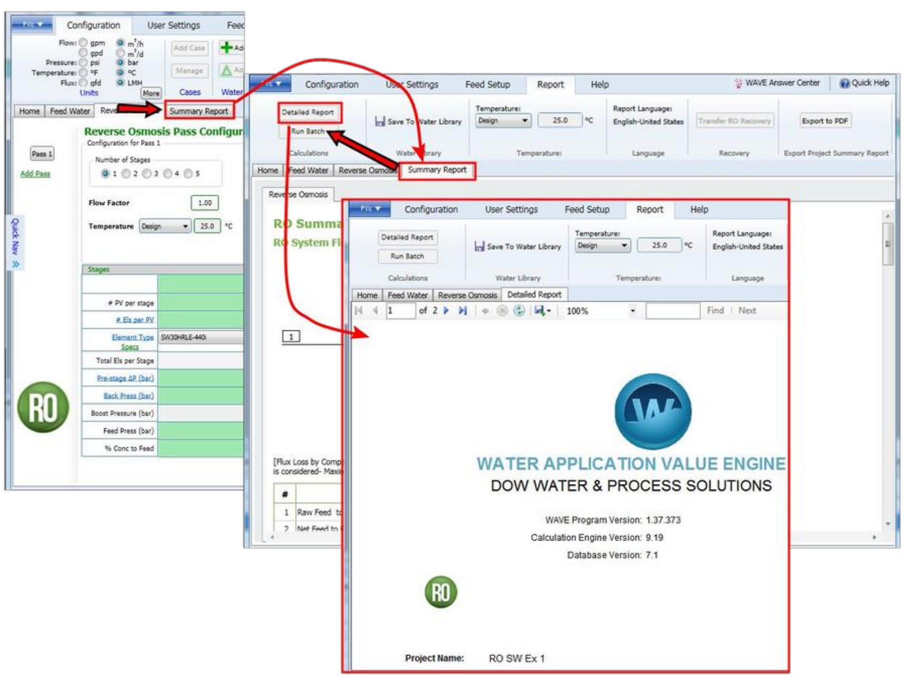
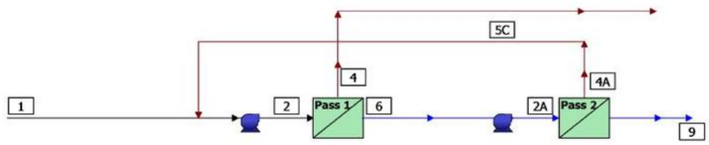


Figure 149. Generation of Detailed Reports in WAVE

Detailed Report Components are given on page 2 of the report and are shown below.

RO Detailed Report

RO System Flow Diagram



#	Description	Flow (m³/h)	TDS (mg/L)	Pressure (bar)	#	Description	Flow (m³/h)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to Pump	54.45	149	0.00	2A	Net Feed to Pass 2	43.02	0.9	12.96
2	Net Feed to Pass 1	61.47	133	6.87	4A	Total Concentrate from Pass 2	7.03	3.2	7.81
4	Total Concentrate from Pass 1	18.44	440	6.54	5C	Concentrate Recycle from Pass 2 to Pass 1	7.03	3.2	7.81
6	Total Permeate from Pass 1	43.03	0.88	0.00					
9	Product before Use for UF	36.00	0.5	-					

Further details of the simulation results are given below.

RO System Overview

Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	66.10 %
System Flow Rate	(m³/h)	Net Feed =	54.45	Net Product =	36.00		

Flows, stream concentrations and scaling risks are detailed per pass. More flow details are provided at the Stage level and Element level for each pass.

Pass		Pass 1	Pass 2
Water Type		Surface (SDI < 3)	RO Permeate SDI < 1
Number of Elements		54	24
Total Active Area	(m²)	2006.71	981.06
Feed Flow per Pass	(m³/h)	61.47	43.02
Feed TDS	(mg/L)	133	0.9
Feed Pressure	(bar)	6.87	12.96
Flow Factor		0.95	1.00
Permeate Flow per Pass	(m³/h)	43.03	36.00
Pass Average flux	(LMH)	21.4	36.7
Permeate TDS	(mg/L)	0.88	0.51
Pass Recovery		70.0 %	83.7 %
Average NDP	(bar)	6.05	10.58
Specific Energy	(kWh/m³)	0.43	0.58
Temperature	(°C)	12.0	12.0
pH		7.20	5.24
Chemical Dose			
RO System Recovery		66.1 %	
Net RO System Recovery		66.1%	
Specific Energy	(kWh/m³)	1.10	

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow	Recirc Flow	Feed Press	Boost Press	Conc Flow	Conc Press	Press Drop	Perm Flow	Avg Flux	Perm Press	Perm TDS
			PV	(m³/h)	(m³/h)	(bar)	(bar)	(m³/h)	(bar)	(bar)	(m³/h)	(LMH)	(bar)	(mg/L)
1	ECO PRO 400	6	6	61.47	0.00	6.53	0.00	34.17	5.73	0.80	27.31	20.4	0.20	0.89
2	ECO PRO 400	3	6	34.17	0.00	7.45	2.07	18.44	6.54	0.91	15.72	23.5	0.00	0.85

In case of permeate split, WAVE does not create an additional element; instead it 'extends' or 'shrinks' the adjoining elements so that the number of elements in the pressure vessel remains constant. The elements marked in the asterisks are thus virtual elements.

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (m³/h)	Recirc Flow (m³/h)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m³/h)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m³/h)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1F	ECO PRO 400	6	1.07*	60.06	0.00	6.31	0.00	54.98	6.13	0.18	5.08	21.1	0.33	0.9
1R	ECO PRO 400	6	4.93*	54.98	0.00	6.13	-	33.37	5.53	0.59	21.61	19.9	0.20	0.9
2	ECO PRO 400	3	6	33.37	0.00	7.26	2.07	18.02	6.38	0.88	15.35	22.9	0.00	0.86

* Design includes Permeate Split. Please refer to the RO System Diagram.

Solute concentration is given in a below table:

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)								
		Adjusted Feed		Concentrate		Permeate		
	Raw Feed	Initial	After Recycle	Stage1	Stage2	Stage1	Stage2	Total to Pass 2
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K^+	1.40	1.40	1.25	2.23	4.13	0.01	0.01	0.01
Na^+	9.00	9.00	8.01	14.36	26.56	0.06	0.05	0.06
Mg^{+2}	5.00	5.00	4.44	7.97	14.76	0.01	0.01	0.01
Ca^{+2}	21.00	21.00	18.64	33.48	61.99	0.06	0.05	0.05
Sr^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_3^{-2}	0.06	0.06	0.05	0.16	0.58	0.00	0.00	0.00
HCO_3^-	74.82	74.82	66.50	119.20	219.96	0.69	0.66	0.68
NO_3^-	1.00	1.00	0.89	1.60	2.95	0.01	0.01	0.01
Cl^-	8.00	8.00	7.10	12.76	23.62	0.02	0.02	0.02
F^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2}	20.00	20.00	17.73	31.88	59.04	0.03	0.02	0.02
Br^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	8.43	8.43	8.47	8.53	8.73	8.24	8.32	8.27
SiO_2	9.00	9.00	7.98	14.35	26.56	0.01	0.02	0.01
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS	149	149	133	238	440	0.89	0.85	0.88
pH	7.20	7.20	7.15	7.38	7.62	5.24	5.22	5.24

RO Design Warnings

None

RO Flow Table (Element Level) - Pass 1

Stage	Element	Recovery (%)	Feed Flow (m³/h)	Feed Press (bar)	Feed TDS (mg/L)	Conc Flow (m³/h)	Perm Flow (m³/h)	Perm Flux (LMH)	Perm TDS (mg/L)
1	1	7.81	10.25	6.53	133	9.45	0.80	21.5	0.90
1	2	8.25	9.45	6.35	144	8.67	0.78	21.0	0.90
1	3	8.78	8.67	6.19	157	7.91	0.76	20.5	0.90
1	4	9.44	7.91	6.05	172	7.16	0.75	20.1	0.90
1	5	10.28	7.16	5.93	189	6.42	0.74	19.8	0.90
1	6	11.35	6.42	5.82	211	5.69	0.73	19.6	0.90
2	1	8.09	11.39	7.45	238	10.47	0.92	24.8	0.80
2	2	8.57	10.47	7.25	259	9.57	0.90	24.1	0.80
2	3	9.15	9.57	7.07	283	8.70	0.88	23.6	0.80
2	4	9.89	8.70	6.91	312	7.84	0.86	23.1	0.90
2	5	10.82	7.84	6.77	346	6.99	0.85	22.8	0.90
2	6	12.02	6.99	6.65	387	6.15	0.84	22.6	0.90

RO Flow Table (Stage Level) - Pass 2

				Feed				Concentrate			Permeate			
Stage	Element	#PV	#Els per PV	Feed Flow (m^3/h)	Recirc Flow (m^3/h)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m^3/h)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m^3/h)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1	ECO PRO 440	3	6	43.02	0.00	12.76	0.00	14.65	10.57	2.19	28.38	38.6	0.00	0.50
2	ECO PRO 440	1	6	14.65	0.00	10.37	0.00	7.03	7.81	2.56	7.63	31.1	0.00	0.53

Solute Concentrations - Pass 2

Concentrations (mg/L as ion)						
		Concentrate		Permeate		
	Feed	Stage1	Stage2	Stage1	Stage2	Total
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00
K^+	0.01	0.02	0.05	0.00	0.00	0.00
Na^+	0.06	0.16	0.32	0.00	0.01	0.00
Mg^{+2}	0.01	0.04	0.08	0.00	0.00	0.00
Ca^{+2}	0.05	0.16	0.32	0.00	0.00	0.00
Sr^{+2}	0.00	0.00	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00	0.00	0.00
CO_3^{-2}	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3^-	0.68	1.14	2.00	0.49	0.51	0.49
NO_3^-	0.01	0.03	0.05	0.00	0.00	0.00
Cl^-	0.02	0.05	0.11	0.00	0.00	0.00
F^-	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2}	0.02	0.07	0.15	0.00	0.00	0.00
Br^-	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	8.27	8.62	8.79	8.05	8.35	8.11
SiO_2	0.01	0.04	0.08	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00	0.00	0.00
TDS	0.9	1.71	3.16	0.50	0.53	0.51
pH	5.24	5.44	5.67	5.11	5.11	5.11

RO Flow Table (Element Level) - Pass 2

Stage	Element	Recovery (%)	Feed Flow (m^3/h)	Feed Press (bar)	Feed TDS (mg/L)	Conc Flow (m^3/h)	Perm Flow (m^3/h)	Perm Flux (LMH)	Perm TDS (mg/L)
1	1	11.71	1.68	12.76	0.9	12.66	1.68	41.1	0.50
1	2	12.76	1.62	12.17	0.9	11.05	1.62	39.5	0.50
1	3	14.20	1.57	11.69	1.0	9.48	1.57	38.4	0.50
1	4	16.22	1.54	11.29	1.1	7.94	1.54	37.6	0.50
1	5	19.21	1.53	10.98	1.2	6.42	1.53	37.3	0.50
1	6	23.88	1.53	10.74	1.4	4.88	1.53	37.5	0.50
2	1	9.61	1.41	10.37	1.7	13.25	1.41	34.5	0.50
2	2	10.08	1.34	9.76	1.8	11.91	1.34	32.7	0.50
2	3	10.71	1.28	9.23	2.0	10.64	1.28	31.2	0.50
2	4	11.56	1.23	8.77	2.2	9.41	1.23	30.1	0.50
2	5	12.73	1.20	8.39	2.4	8.21	1.20	29.3	0.50
2	6	14.38	1.18	8.07	2.8	7.03	1.18	28.9	0.50

RO Solubility Warnings

None

RO Chemical Adjustments

	Pass 1 Feed	RO 1st Pass Conc	Pass 2 Feed	RO 2 ND Pass Conc
pH	7.20	7.62	5.24	5.67
Langelier Saturation Index	-1.42	-0.12	-7.93	-6.26
Stiff & Davis Stability Index	-0.31	0.61	-4.79	-3.63
TDS (mg/l)	149	440	0.9	3.2
Ionic Strength (molal)	0.00	0.01	0.00	0.00
HCO_3^- (mg/L)	74.82	219.96	0.68	2.00
CO_2 (mg/l)	8.43	8.73	8.27	8.79
CO_3^{-2} (mg/L)	0.06	0.58	0.00	0.00
$CaSO_4$ (% saturation)	0.11	0.88	0.00	0.00
$BaSO_4$ (% saturation)	0.00	0.00	0.00	0.00
$SrSO_4$ (% saturation)	0.00	0.00	0.00	0.00
CaF_2 (% saturation)	0.00	0.00	0.00	0.00
SiO_2 (% saturation)	9.09	26.84	0.01	0.07
$Mg(OH)_2$ (% saturation)	0.00	0.00	0.00	0.00

Costs are reported for the RO system as shown below.

The service water costs have two components:

- Non-product feed water – this is water that the plant would have paid to get but would not be using (because it is discharged).
- Waste water – this is water that the plant has to pay to remove from the premises

RO Utility and Chemical Costs

Service Water

	Flow Rate (m³/h)	Unit Cost ($/m³)	Cost ($/hr)	Cost ($/d)
Non-Product Feed Water				
Pass 1	18.44	0.14	2.58	61.97
Pass 2	0.00	0.14	0.00	0.00
Total Non-product Feed Water Cost	18.44		2.58	61.97
Waste Water Disposal				
Pass 1	18.44	0.69	12.73	305.41
Pass 2	0.00	0.69	0.00	0.00
Total Waste Water Disposal	18.44		12.73	305.41
Total Service Water Cost				367.38

Electricity

Peak Power	(kW)	39.65
Energy	(kWh/d)	951.51
Electricity Unit Cost	($/kWh)	0.09
Electricity Cost	($/d)	85.64
Specific Energy	(kWh/m³)	1.10

Pump	Flow Rate (m³/h)	Power (kW)	Energy (kWh/d)	Cost ($/d)
Pass 1				
Feed	61.47	15.94	382.52	34.43
Stage 2 Boost	34.17	2.67	64.00	5.76
Pass 1 Total Electrical Cost		18.61	446.52	40.19
Pass 2				
Feed	43.02	21.04	504.99	45.45
Pass 2 Total Electrical Cost		21.04	504.99	45.45

Chemical

Chemical	Unit Cost ($/kg)	Dose (mg/L)	Volume (L/d)	Cost ($/d)
Total Chemical Cost				0.00

Utility and Chemical Cost	($/d)	453.02
Specific Water Cost	($/m³)	0.52

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Even though in simple systems the non-product feed water and the waste water are the same, in more complicated systems they would not be. For instance, if extensive chemical cleaning is used in RO to maintain recovery, the non-product feed water cost would remain the same but the wastewater disposal cost would increase.

4.2.3 Modification of System Design after Calculation

WAVE makes possible regeneration of the report through:

Modification of the Feed Temperature

After the first simulation of the system, a WAVE user can rerun the simulation at a different temperature by following these steps (Figure 150:

1. Click on the dropdown arrow under "Temperature" in the Summary Report Tab.
2. Select the appropriate temperature value:
    a. Design temperature
    b. Maximum temperature
    c. Minimum temperature
    d. Another values (using the 'Specify') option.
3. Click on the "Summary Report" button.

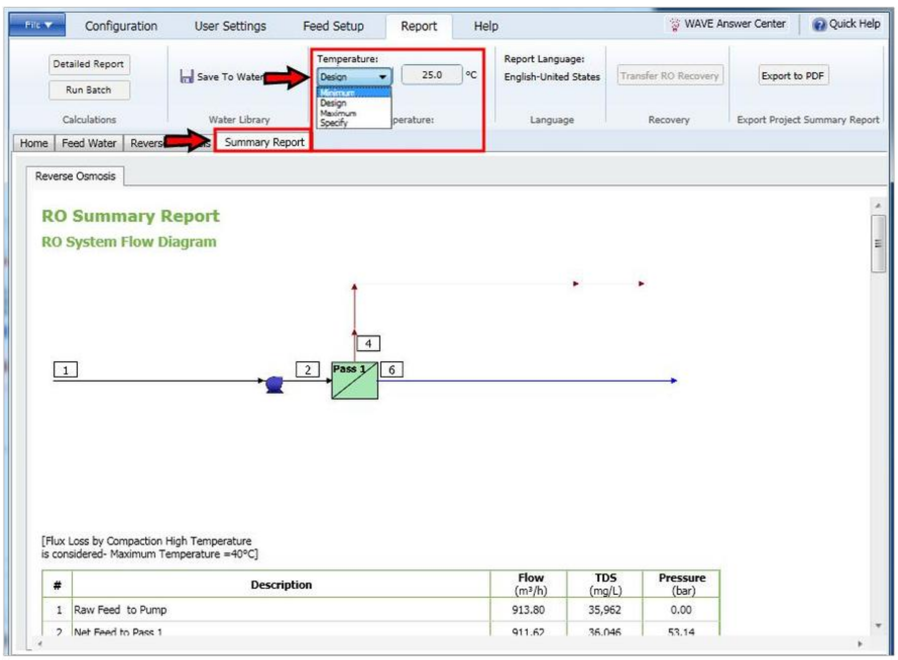

Figure 150. WAVE report regeneration and addition simulation by changing feed temperature

4. The report will be updated with recalculated values.

Notes:

- The same Minimum, Maximum and Design Temperatures specified in the Feed Water Tab would be shown in the dropdown list in the Report Tab.
- The temperature specified at this step would not be propagated to other windows (e.g. the Chemical Adjustment Popup Window)

Modification of the System Recovery

WAVE makes it possible to send the System Recovery calculated at the Report Tab to the Home Tab to be used for additional work. This can be done through the following steps (as shown in Figure 151):

1. After running a report, click on the Home Tab and right-click on the Technology symbol
2. Select "Define Recovery" from the dropdown list. The Define Recovery Popup Window would appear.
3. Select the radio button next to "Use Last Calculated Value" and click "OK"
4. Click on the Report Tab

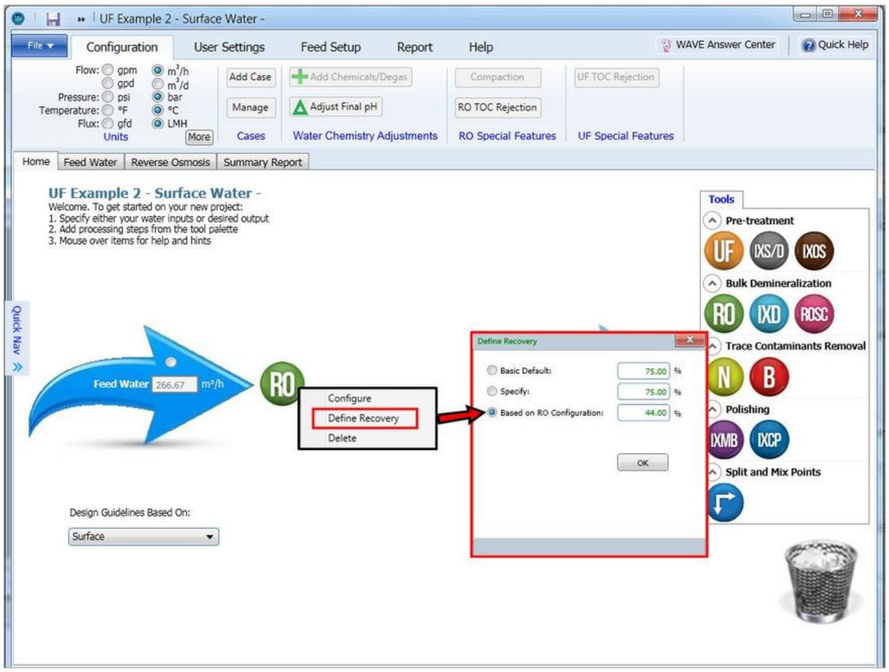

Figure 151. WAVE report regeneration and additional simulation by changing recovery; Updating estimated System Recovery and Selecting the new estimated System Recovery

Note: The "Update Estimated Recovery" button only updates the System Recovery.

4.2.4 Handling the Reports (Saving and Exporting)

The Summary Report serves as a quick look at the results.

The Summary Report can be exported as a PDF document to a folder location of the user's choice (Figure 152).

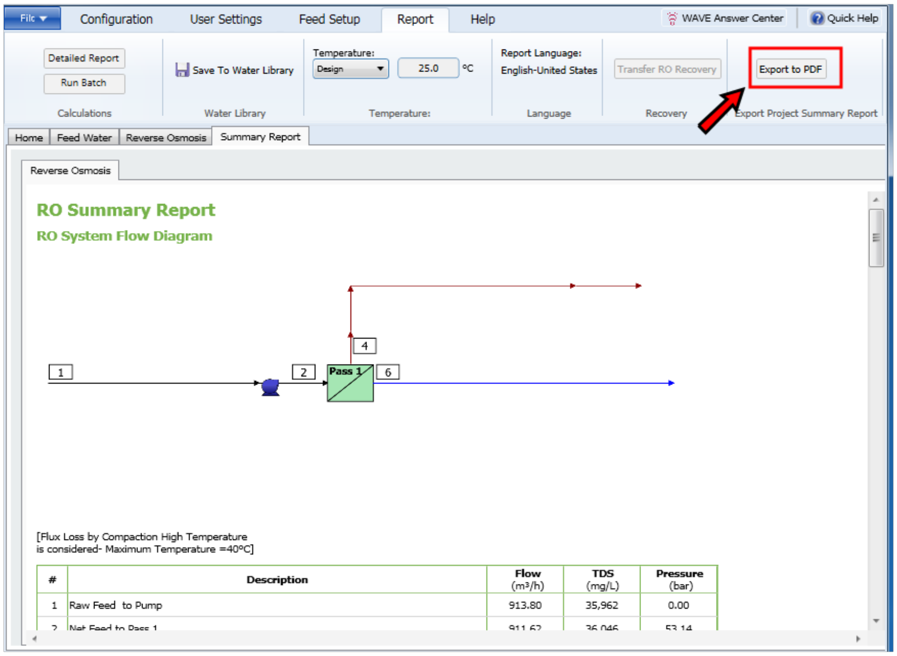

Figure 152. Export. of Summary Report in WAVE as PDF

The Detailed Report can be exported to PDF or to Excel, Word or PDF as shown in Figure 153 and Figure 154. All of these options lead to a folder location where the user can save the PDF, Excel or Word file.

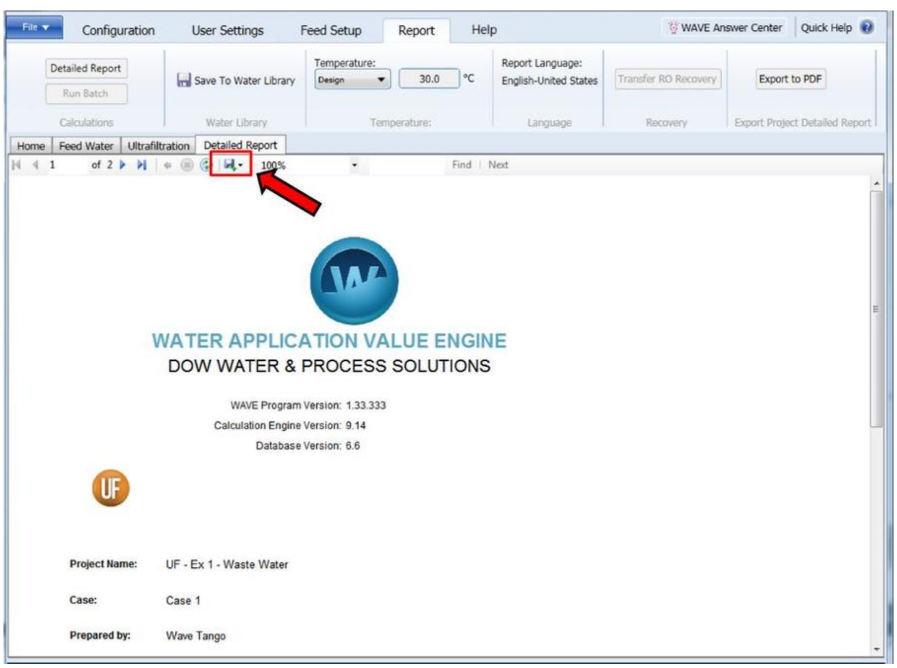

Figure 153. Export of Detailed Reports in WAVE - selecting the dropdown

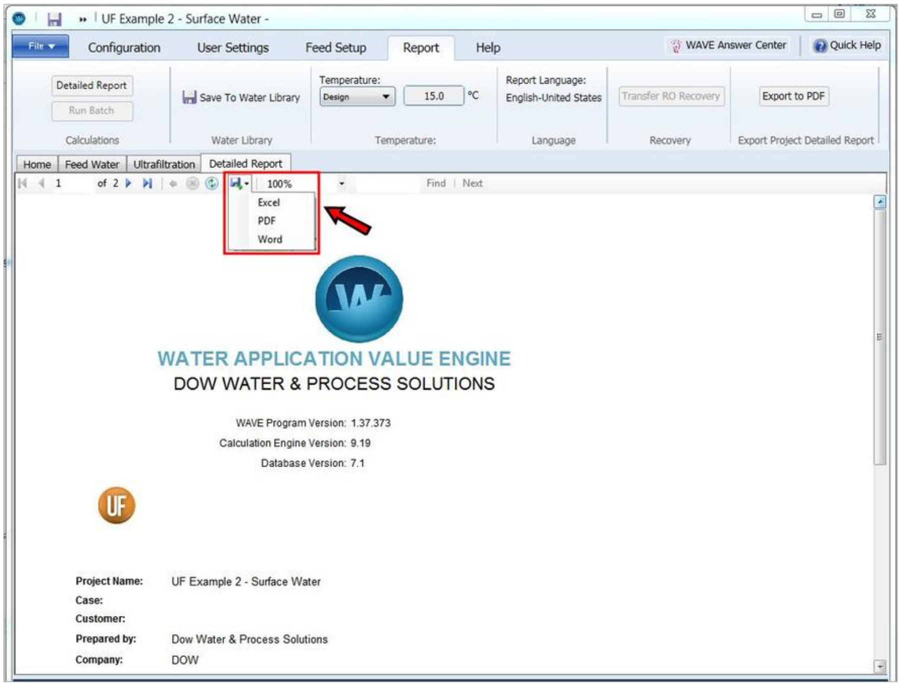

Figure 154. Export of Detailed Reports in WAVE - selecting the option

5 Ion Exchange

The Ion Exchange (IX) system design in WAVE allows sizing of new systems, evaluating the performance of existing ones and retrofitting existing plants to the UPCORE™ system. In order to design a new Ion Exchange system, it is important to understand the main inputs needed to help obtain an accurate and optimized design. These inputs include information about the feed water composition, required feed water or product water flow rate, vessels and regeneration system, regeneration conditions and product.

Once all this information is introduced in the system design software, it will populate a detailed Ion Exchange System Design report which includes a general process flow diagram, resins properties, sizing of vessels, regeneration protocols, water quality and estimation of chemicals and energy consumption, among others.

IX system specification includes the following steps:

5.1 Ion Exchange System Specification

Ion Exchange system specification includes the following steps:

5.1.1 Adding IX Process Icons into the WAVE Home Window

The relevant IX icon can be dragged and dropped on top of the gray spot to specify a specific IX process (e.g. IXS/D, IXD, IXMB) as shown in Figure 155. If the gray spot is not visible, simply dragging the relevant IX icon between the two large blue arrows will make the gray spot visible.

WAVE provides the following IX process options:

- IXS/D = Ion Exchange Softening/Dealkalization
- IXOS = Ion Exchange Organic Scavenging
- IXD = Ion Exchange Demineralization
- N = Nitrate Removal
- B = Boron Removal
- IXMB = Ion Exchange Mixed Bed
- IXCP = Ion Exchange Condensate Polishing

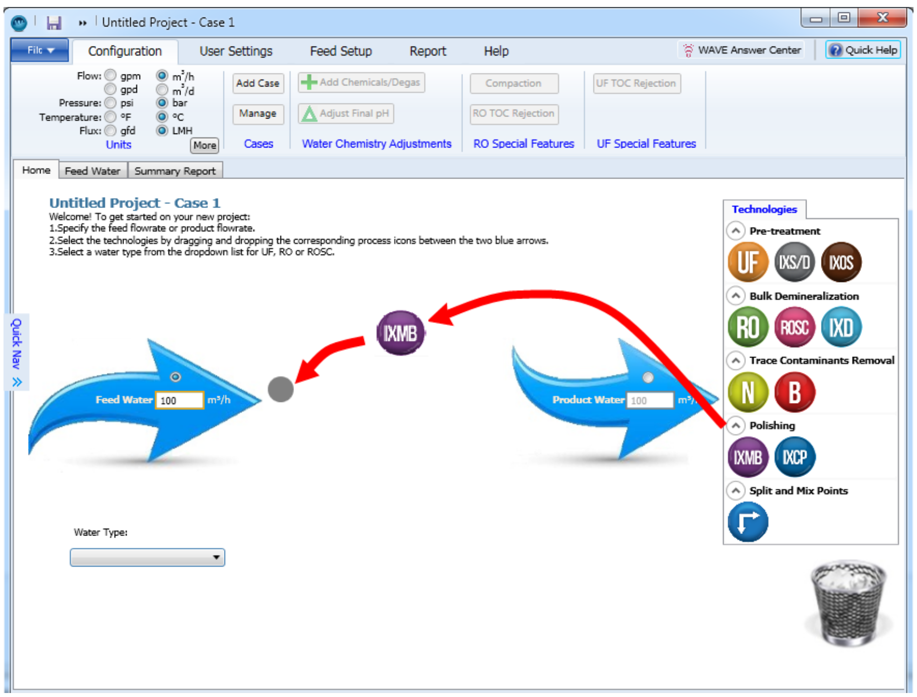

Figure 155. Dragging and dropping IX icon

Notes:

- WAVE will only allow the IX icons associated with Pretreatment to be placed upstream of any WAVE icons (IX or otherwise) associated with Bulk Demineralization, Trace Contaminant Removal or Polishing.
- WAVE will only allow the IX icons associated with Bulk Demineralization to be placed upstream of any WAVE icons (IX or otherwise) associated with Trace Contaminant Removal or Polishing but downstream of the WAVE icons (IX or otherwise) associated with Pretreatment
- WAVE will only allow the IX icons associated with Trace Contaminant Removal to be placed upstream of any WAVE icons (IX or otherwise) associated with Polishing but downstream of the WAVE icons (IX or otherwise) associated with Pretreatment or Bulk Demineralization.

5.1.2 Removing IX Process Icons

There are two ways to remove the IX process icons:

1. Dragging and dropping the icons into the picture of the waste bin
2. Right-clicking on the icon in question and selecting “Delete”

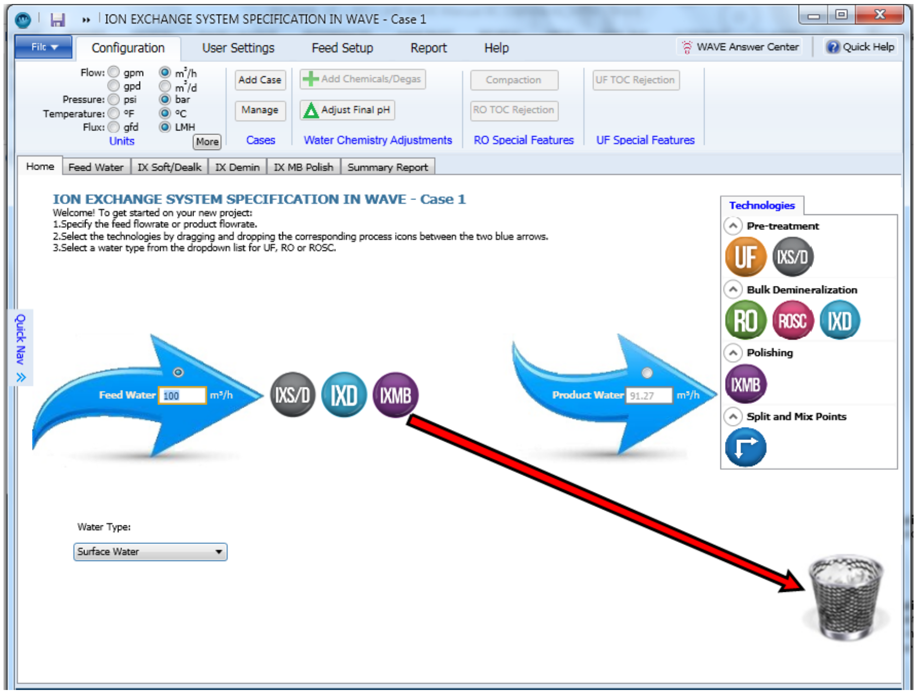

Figure 156. Dragging and dropping the icons into the picture of the waste bin

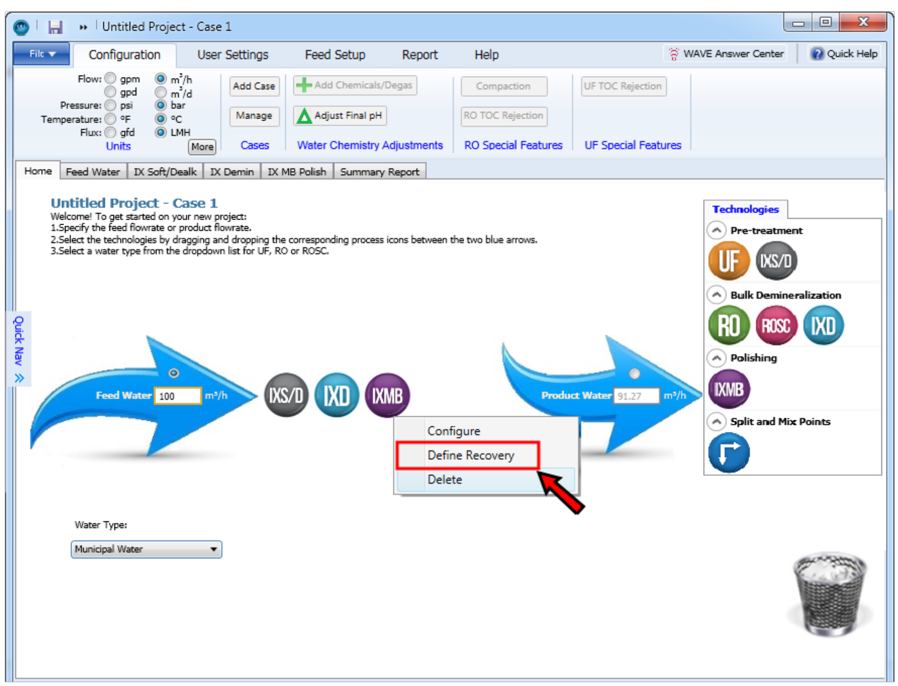

Figure 157. Right-clicking on the icon in question and selecting “Delete”

5.1.3 Defining the Feed Water Flowrates and System Recoveries

Feed and product water flow rates can be specified using the text boxes in the middle of the blue arrows.

Notes:

- WAVE would display a warning if the Feed or Product flow rates are specified as 0 or as a negative number
- Given a feed water flowrate, WAVE would calculate a product flow rate based on a default recovery . In a simlar way, given a product water flowrate, WAVE would calculate a feed flow rate based on a default recovery
- WAVE does not allow simultaneous specification of the feed and product flow rates
- The default system recovery for an IX process is 97% (see section Define Recovery for more information on defining system recovery)

5.1.4 Defining the type of water

See Specifying the Feed Water Composition for information on defining the feed water type and composition.

5.1.5 The IX Initialization Window: Defining the Modeling Objective, Train Configuration and Regeneration Frequency

The IX Initialization Window allows the WAVE user to specify:

The Modeling Objective

WAVE can be used in three different ways to model IX processes (as shown in Figure 158):

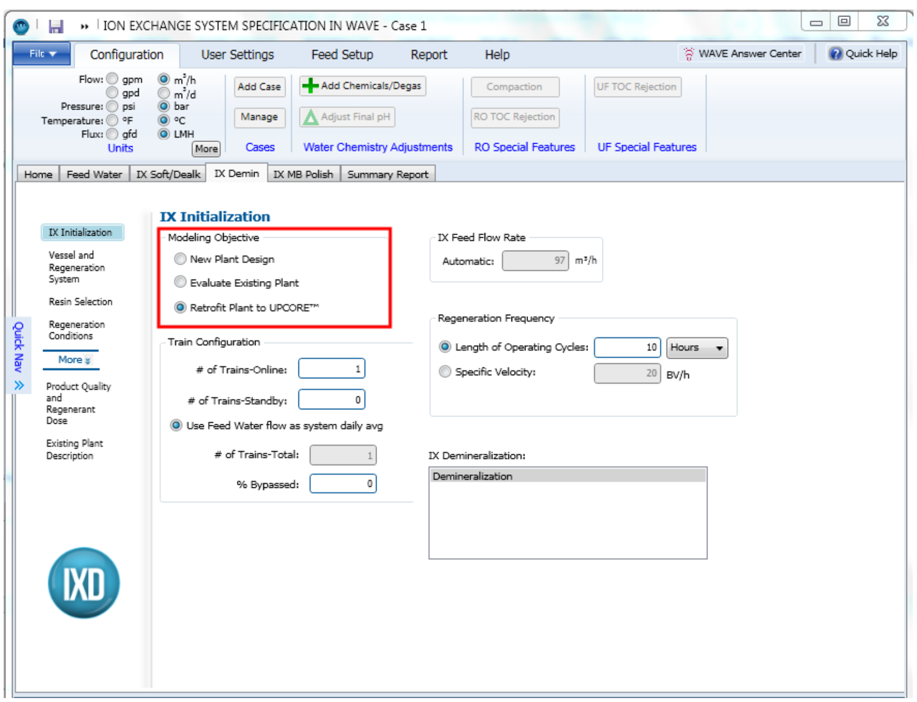

Figure 158. IX Initialization Window

1. New Plant Design: according to user inputs a resin volume or an operating cycle will be calculated to meet the specifications.

2. Evaluate Existing Plant: according to the existing plant details, the performance of one point in time will be evaluated (runtime is fixed). Alternatively, WAVE will try to find the maximum runtime to meet the specified leakage and operating capacity according to the existing plant details (runtime is optimized).

3. Retrofit Plant to a UPCORE™ system: according to the existing plant design, the plant can be retrofitted to incorporate the UPCORE™ technology. Given vessel sizing, resin volume and performance will be calculated.

New Plant Design*: according to user inputs a resin volume or an operating cycle will be calculated to meet the specifications. Click for more detail.*

From the IX Initialization Window, select "New Plant Design" option. This option allows the user to design a new plant. The key design parameters needed to design ion exchange systems are feed water quality, feed water or product water flow rate, chemicals quantity, and the number of vessels and trains. There is not a unique solution for the design, as there are several tradeoffs that can be made.

Evaluate Existing Plant: according to the existing plant details, the performance of one point in time will be evaluated (runtime is fixed). Alternatively, WAVE will try to find the maximum runtime to meet the specified leakage and operating capacity according to the existing plant details (runtime is optimized). Click for more detail.

Evaluate Existing Plant:

- From the IX Initialization Window, select "Evaluate Existing Plant" option.
- A new window called "Existing Plant Description" will be added at the bottom of the left-hand navigation area, as shown in Figure 159.

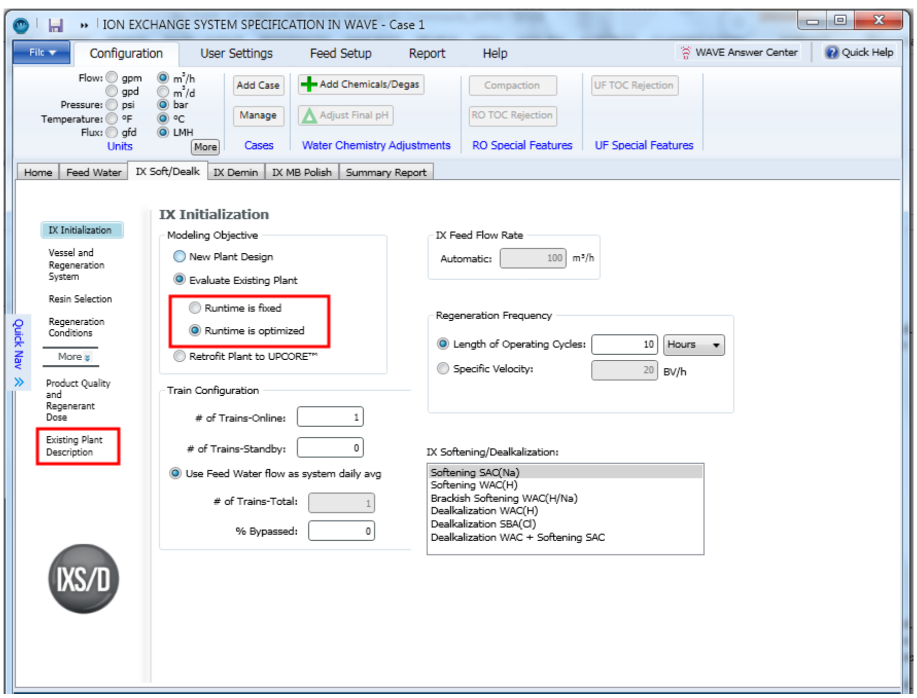

Figure 159. IX Initialization Window. The Modeling Objective: Evaluate Existing Plant

Run Time specification: Once "Evaluate Existing Plant" option is selected, the modeling objective must be specified as follow (see Figure 159):

1. Runtime is fixed: according to existing plant details, the product water quality at one point in time (the specified runtime) will be evaluated.

2. Runtime is optimized: the software will calculate the maximum runtime to meet the specified leakage and operating capacity according to the existing plant details.

***Retrofit plant to an UPCORE™ system**: according to the existing plant design, the plant can be retrofitted to incorporate the UPCORE™ technology. Given vessel sizing, resin volume and performance will be calculated. Click for more information*

- From the IX Initialization Window, select "Retrofit Plant to UPCORE™" option. This option allows the user to convert any existing plant to an UPCORE™ design.
- The key design parameters needed to retrofit an existing plant are feed water quality, feed water or product water flow rate, quantity chemicals, and the vessels sizing.

Note: Selecting either Evaluate Existing Plant or Retrofit Plant to UPCORE™ will add an eighth button called Existing Plant Description to the left-hand navigation area (see Figure 159). For more details about this Window see Existing Plant Description

Train Configuration

The Train Configuration section of the IX Initialization window allows the user to specify the number of trains Online and in Standby.

In the case of no Standby trains, the following selection should be made (as shown in Figure 160):

1. Use Feed Water flow as system daily average: this means that IX operating flow will be higher than the specified, as some time for regeneration is required.
2. Use Feed Water flow for vessel design: this means that IX daily average flow will be smaller than the specified, as some time for regeneration is required.

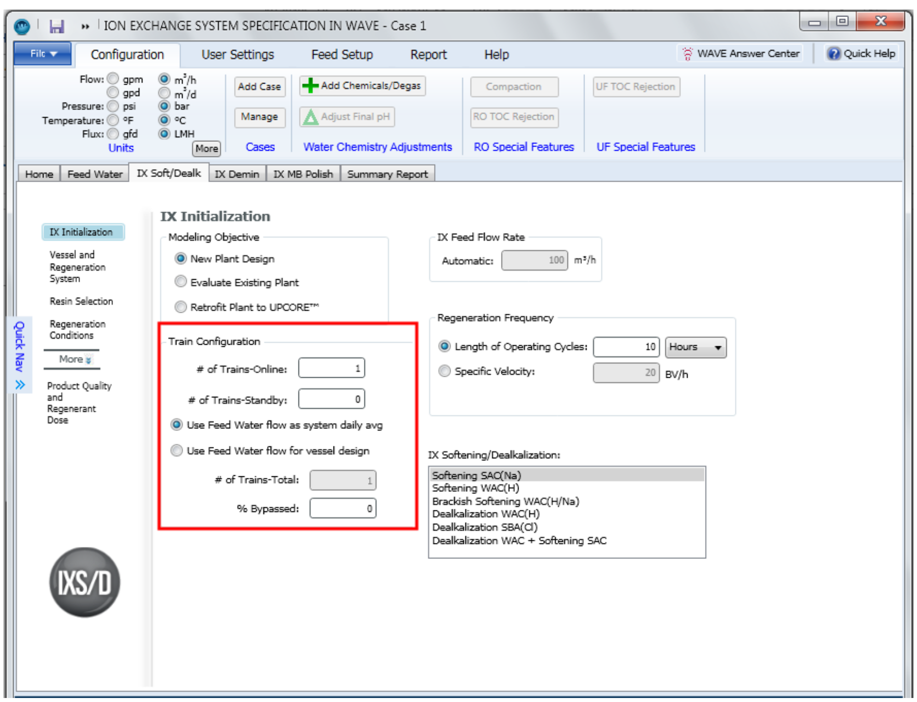

Figure 160. Train Configuration

Note: In multicomponent designs, if there are no Standby trains, the only available option will be "Use Feed Water flow as system daily average". Therefore, the IX operating flow will be higher than the specified, as some time for regeneration is required.

In case that a standby train is used, input flow would equal the operating flow.

If desired, certain percentage of feed flow could also bypass the mix bed. This is shown Figure 161

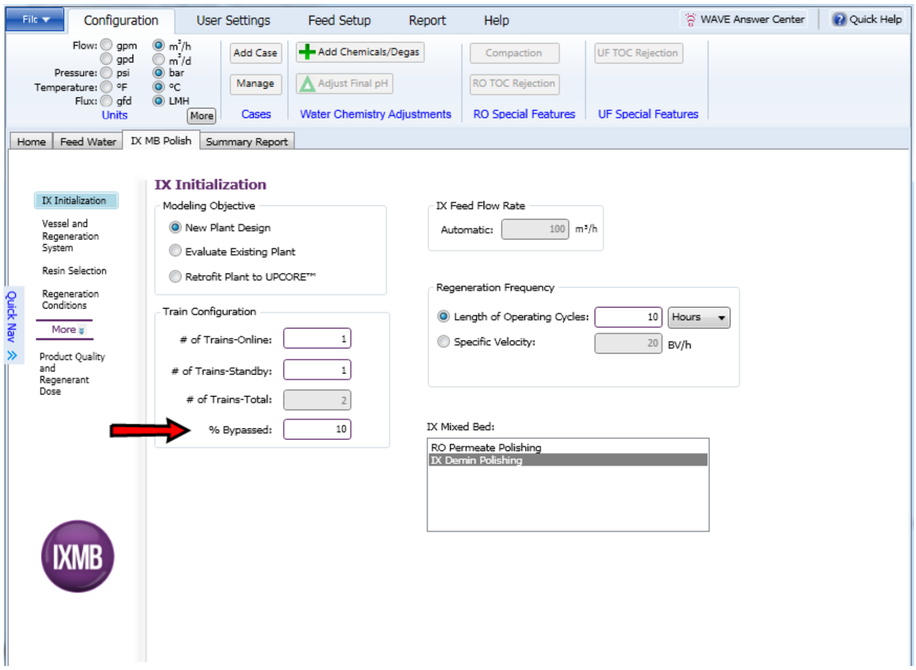

Figure 161. Bypass flow

IX Flow Rate

The IX Flow Rate section of the IX Initialization window shows either:

- The IX Feed Flow Rate: If the Feed Water is specified in the Home tab (see Figure 162).
- The IX Product Flow Rate: If the Product Water is specified in the Home tab (see Figure 163).

Notes:

- If the system daily average option is selected in the Train Configuration section, the value shown for the IX Feed/Product Flow Rate corresponds to the system daily average.
- If the vessel design option is selected in the Train Configuration section, the value shown for the IX Feed/Product Flow Rate corresponds to the design flow rate.

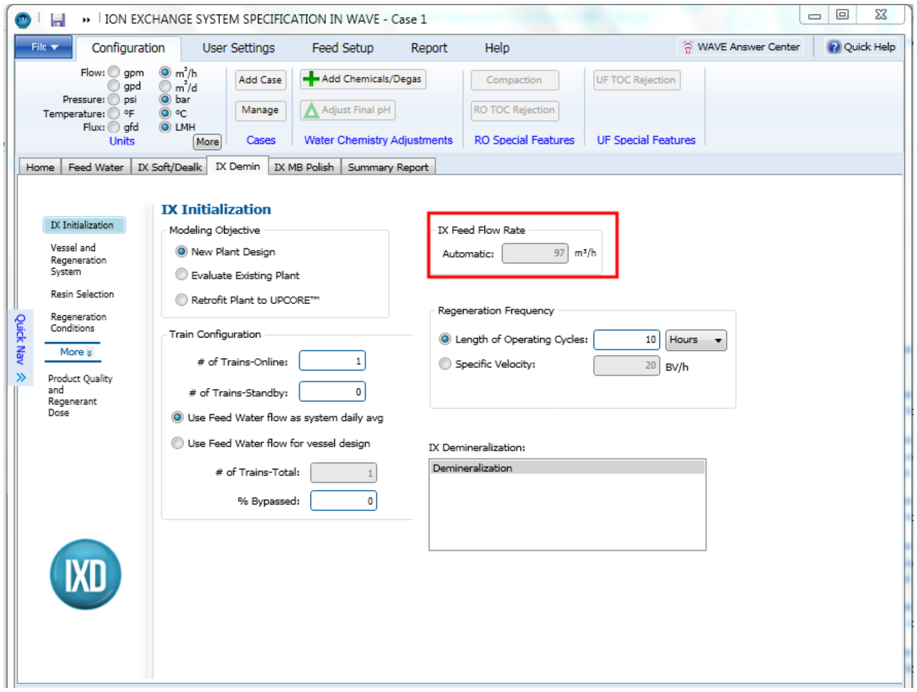

Figure 162. IX Initialization Window. IX Feed Flow Rate

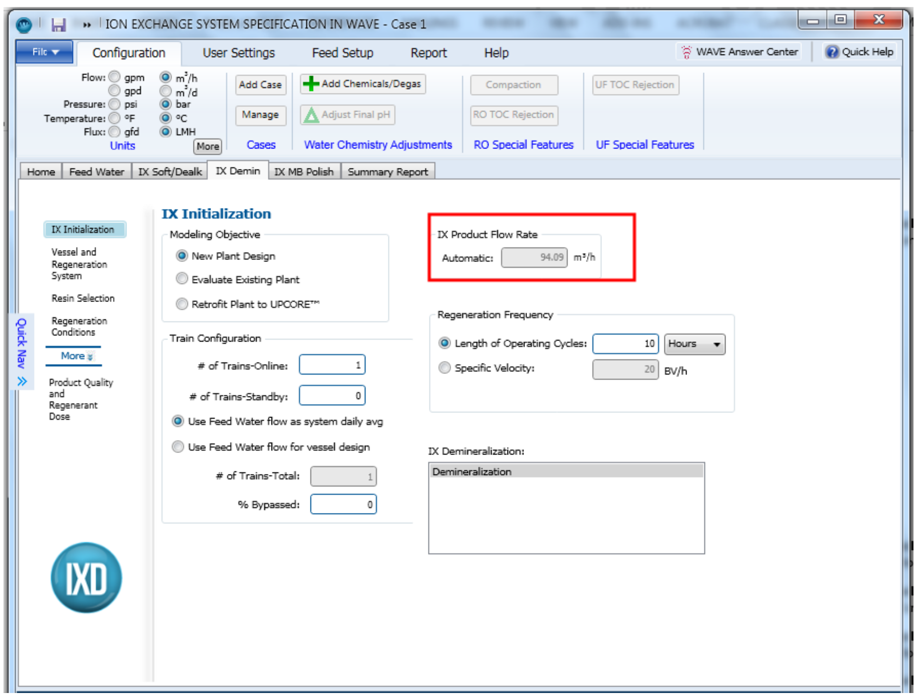

Figure 163. IX Initialization Window. IX Product Flow Rate

Regeneration Frequency

There are two options to set up the regeneration frequency (as shown in Figure 164):

1. Selecting the length of operating cycles (in hours or days): this is the time that the system remains in operation between the end of one regeneration and the beginning of the next regeneration. It calculates the resin volume needed and recommends a vessel size.
2. Selecting the specific velocity (BV/h): according to the operating flow and the specific velocity value, the resin volume would be fixed and the length of operating cycles calculated. It will also recommend the vessel size.

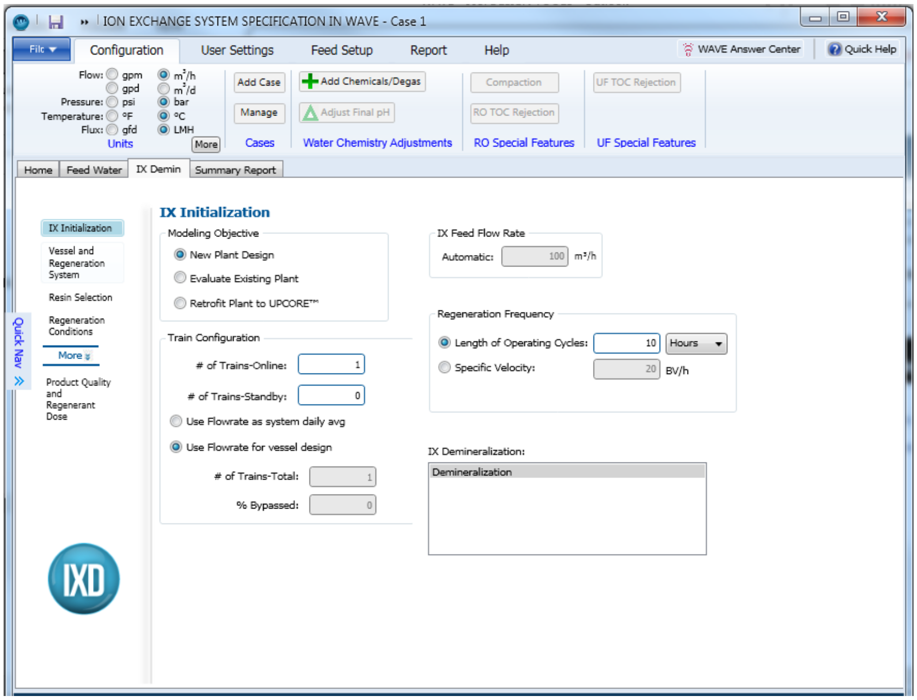

Figure 164. Regeneration Frequency

For the Condensate Polishing (IXCP) process, a third Regeneration Frequency option is available (as shown in Figure 164)

3. Selecting Prebed on Time, Rest on Specific Velocity: the regeneration frequency of the first vessel is defined by the Length of Operating Cycles. The regeneration frequency of the second (and third) vessel is defined by the Specific Velocity.

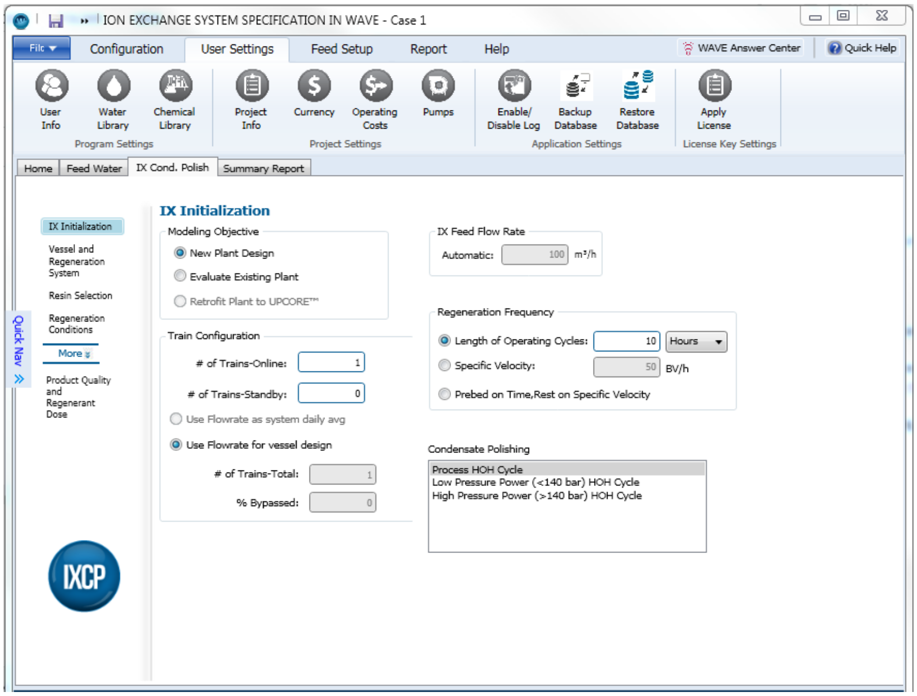

Figure 165. IX Initialization Window. Regeneration Frequency. IX Condensate Polishing

Note: The option "Selecting Prebed on Time, Rest on Specific Velocity" will be gray out until the users specifies the Resin Arrangement in the Vessel and Regeneration System window (see Resin Arrangement). The option "Selecting Prebed on Time, Rest on Specific Velocity" is available for Resin Arrangements with, at least, 2 vessels (i.e. [SAC]-[SBA], [SAC]-[SAC SBA] or [SAC]-[SBA]- [SAC])

Sub-process Option

For some IX applications, WAVE provides additional sub-processes modeling capabilities. Table 3 shows the sub-processes options for the different IX Processes. These can be selected as shown in Figure 166.

Table 3. IX Initialization Window. IX Sub-process.

IX Process	IX Sub-Processes
IXS/D	Softening SAC (Na) Softening WAC (H) Brackish Softening WAC (H/Na) Dealkalization WAC (H) Dealkalization SBA (Cl) Dealkalization WAC + Softening SAC
IXD	Demineralization
IXMB	RO Permeate Polishing IX Demin Polishing
IXCP	Process HOH Cycle Low Pressure Power (< 140 bar) HOH Cycle High Pressure Power (> 140 bar) HOH Cycle

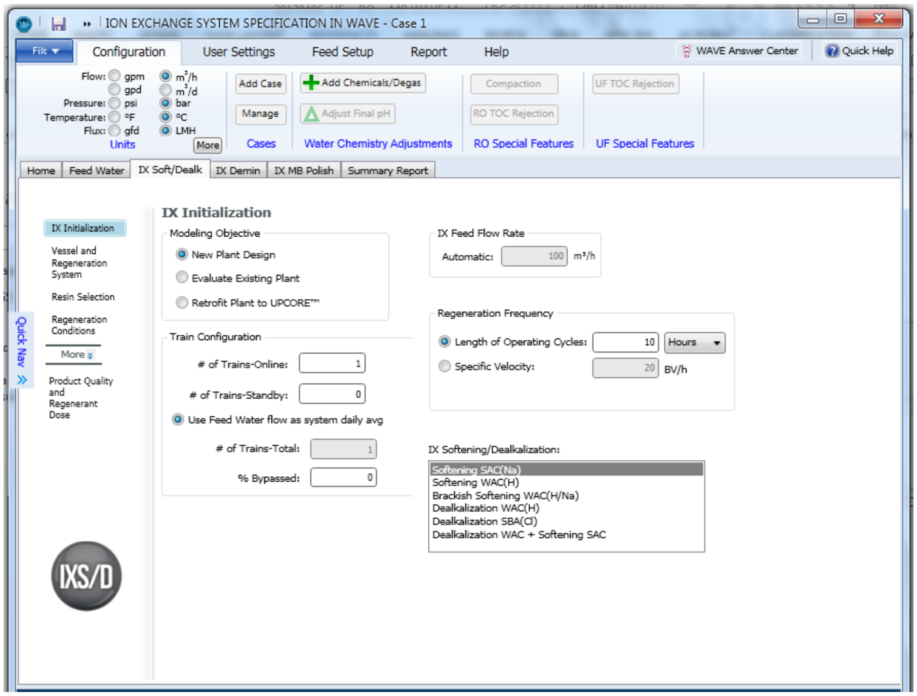

Figure 166. IX Initialization Window. IX Softening/Dealkalization Sub-processes

New Plant Design

This option allows the user to design a new plant from scratch.

Note: Key design parameters for ion exchange systems are water quality, quantity and cost of chemicals, number and geometry of the vessels, and whether all of the resins/vessels can be operated within our design guidelines. There is not a unique solution to the design, as there are several tradeoffs that can be made. This bears some similarity to UF system designs.

5.1.6 Defining the Vessel and Regeneration System

The Vessel and Regeneration System window allows the WAVE user to specify:

Note: The IX System Diagram appears once the Regeneration System has been selected.

Resin Arrangement

The content of the Vessel and Regeneration System screen is dynamic and depends on the type of ion exchange sub-process previously selected in the IX Initialization window. The various combinations of ion exchange resin types are represented in WAVE as follows:

- [XXX] = Resin in a single bed
- [WXX] – [SXX] = Weak resin and Strong resin in separate vessels
- [WXX SXX] = Weak resin and Strong resin in a layered bed (same vessel)
- [WXX | SXX] = Weak resin and Strong resin in single vessel with separated compartments
- [SAC | SBA] = Strong Acid Cation resin and Strong Base Anion resin in single vessel with separated compartments
- [SAC SBA] = = Strong Acid Cation resin and Strong Base Anion resin n in the same vessel (i.e., a Mixed Bed)
- [SAC] - [SBA] = Strong Acid Cation resin and Strong Base Anion resin in separate vessels
- [SAC] - [SAC SBA] = Strong Acid Cation resin in a single bed followed by Strong Acid Cation resin and Strong Base Anion resin in the same vessel (i.e., a Mixed Bed)
- [SAC] - [SBA] – [SAC] = Strong Acid Cation resin, Strong Base Anion resin and Strong Acid Cation resin in separate vessels

WAVE will display the appropriate Resin Arrangement options depending on the IX process and sub-process selected. For example, if the option Softening WAC (H) sub-process was selected in the IX Sub-process section of the IX Initialization window (IXS/D process), only the option WAC will be displayed in the Resin Arrangement section. This is shown in Figure 167.

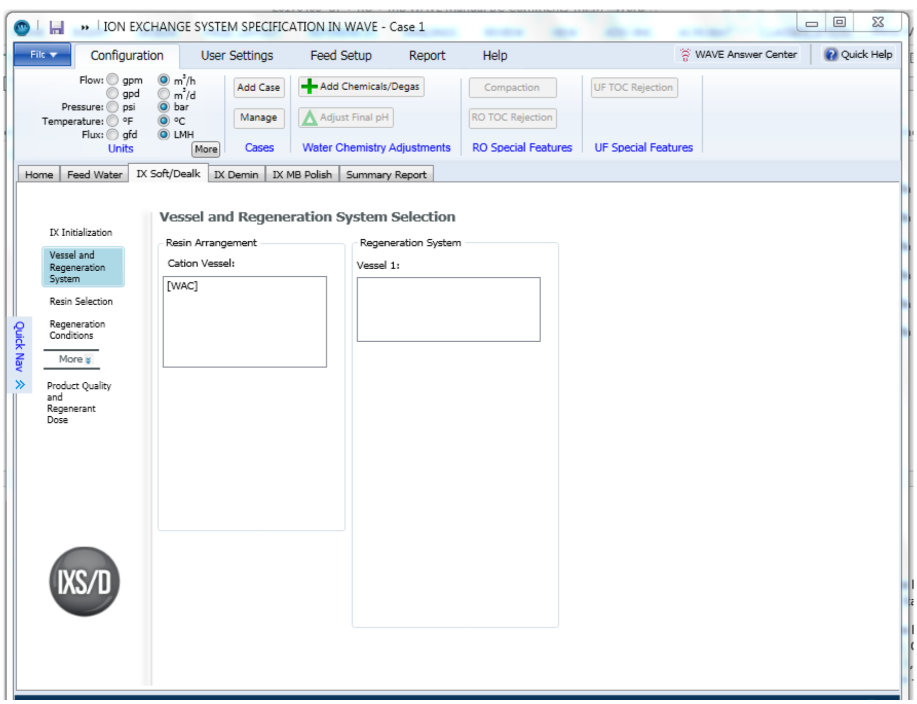

Figure 167. Vessel and Regeneration System. Resin Arrangement options for the Softening WAC (H) sub-process

On the other hand, if the Demineralization option was selected in the IX Sub-process section of the IX Initialization window (IXD process), all the various combinations of ion exchange resin types listed above will be displayed for both cation and anion vessels. This is shown in Figure 168.

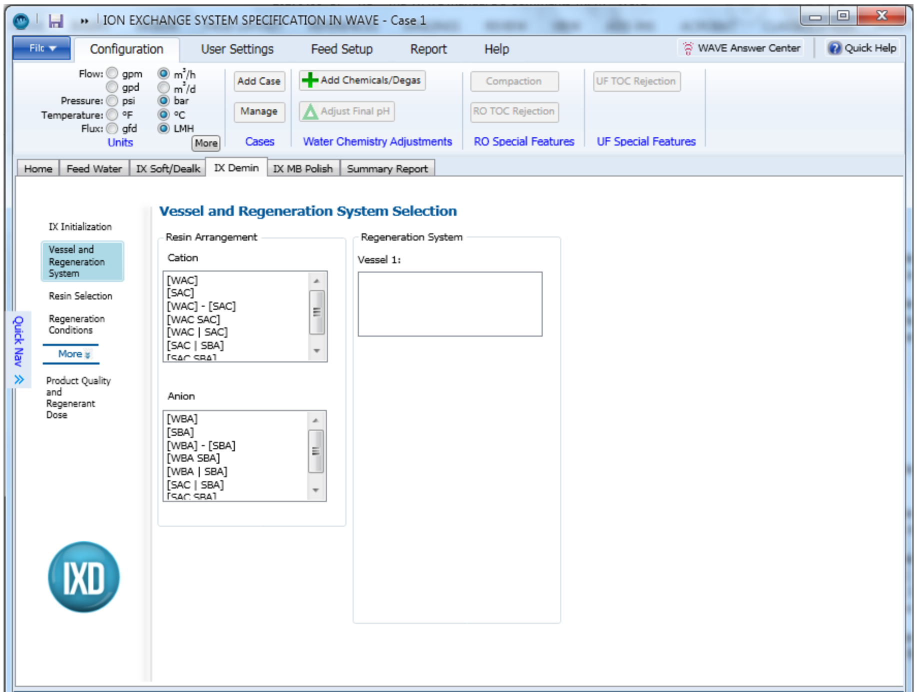

Figure 168. Vessel and Regeneration System. Resin Arrangement options for the Demineralization sub-process

Regeneration System

WAVE allows for the following types of regeneration systems:

- Co-current
- UPCORE™
- AMBERPACK™
- Air Block
- Water Block
- MB: Internal regeneration (only available for mixed beds)
- MB: External regeneration (only available for mixed beds)

WAVE will display the appropriate number of vessels and Regeneration System options depending on the IX sub-process and the Resin Arrangement previously selected. As an example, Figure 169 the figure below shows the Regeneration System options available when the Resin Arrangement [SAC] + [WBA | SBA] is selected in a demineralization design.

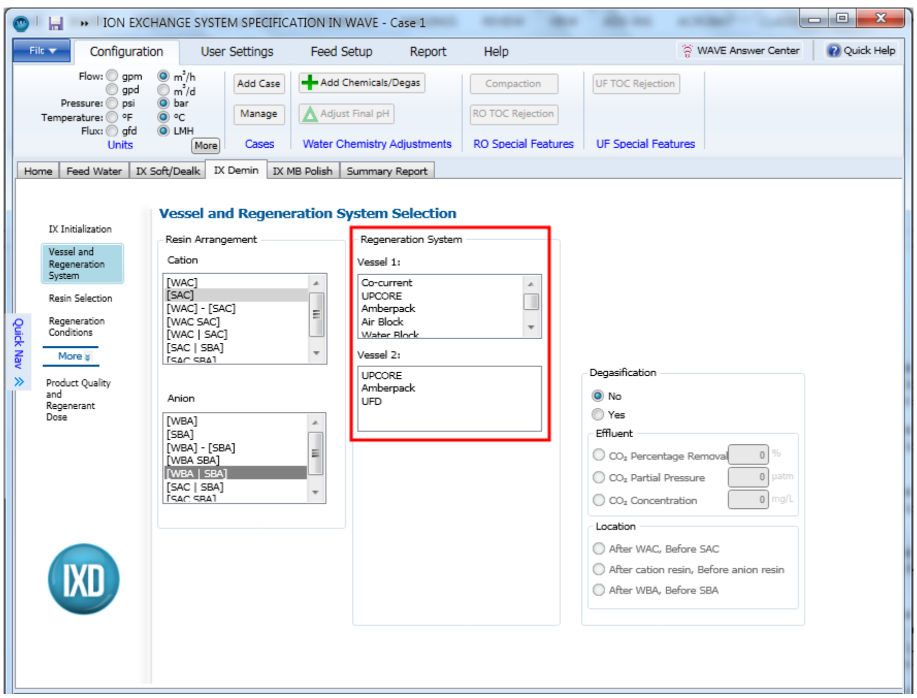

Figure 169. Vessel and Regeneration System. Regeneration System selection for demineralization with [SAC] + [WBA | SBA] Resin Arrangement

Once the user selects the Regeneration System, the IX System Diagram and the Degasification System options appear.

Note: WAVE deactivates some Regeneration System options depending on the Resin Arrangement selected.

Degasification System

The amount of degasification from the IX effluent stream can be quantified in WAVE in terms of (as shown in Figure 170):

- CO_2 Percentage Removal
- CO_2 Partial Pressure
- CO_2 Concentration

WAVE provides the possibility of placing the degasification step at various positions in relation to the IX resin beds for some IX processes (as shown in Figure 170):

- After WAC, before SAC
- After cation resin, before anion resin
- After WBA, before SBA

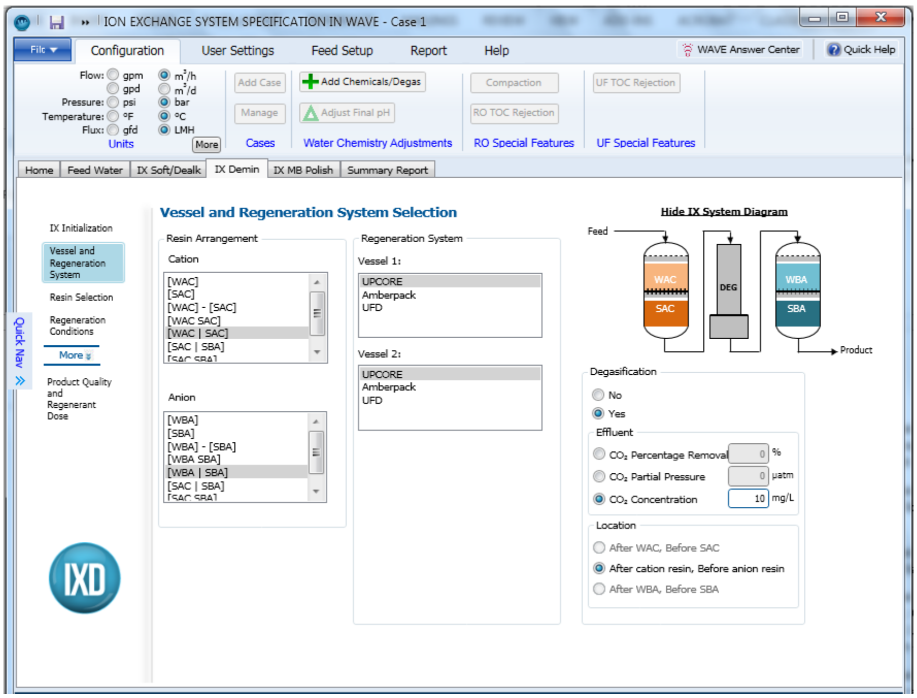

Figure 170. Vessel and Regeneration System. Degasification System selection

Note:

- Degasification is only available for some processes.
- WAVE deactivates some options for placing the degasification depending on the IX Sub-process and the Resin Arrangement selected.

IX Process Flow Diagram

WAVE can display the IX System Diagram in the Vessel and Regeneration System window once the Regeneration System has been selected.

5.1.7 Resin Selection

The user can filter the preferred brand by checking the different options to limit resin choices and make resin selection easier. The user can also select the delivered ionic form and the resin packaging size. These selections can affect the final recommended design.

Notes:

- WAVE will display the suitable resins list depending on the IX Sub-process, Resin Arrangement and Regeneration System selected.
- The IX process flow diagram can be displayed by clicking on the "Show IX System Diagram" button (see Figure 165).

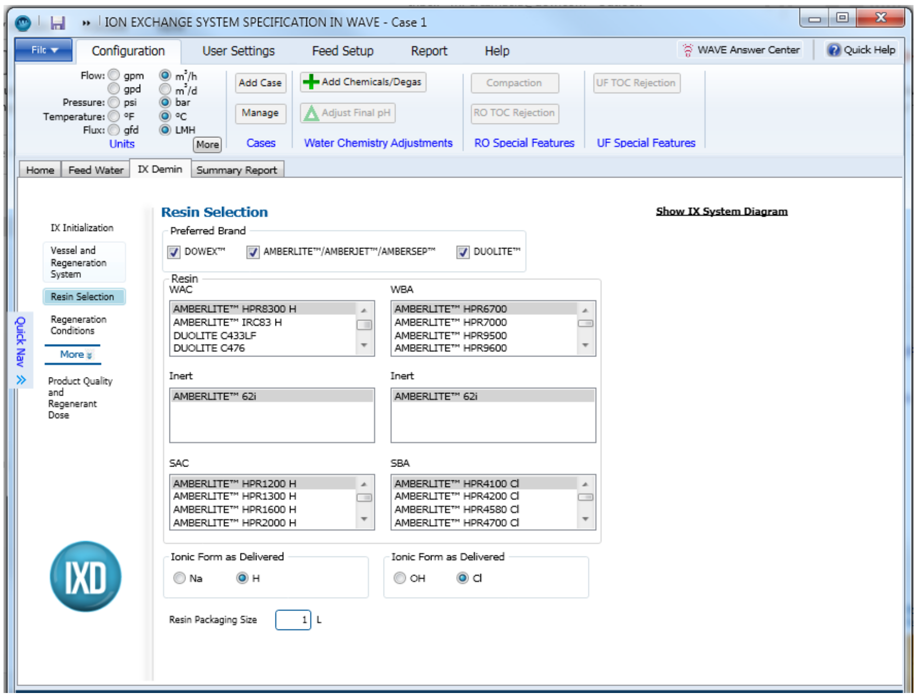

Figure 171. Resin Selection

5.1.8 Defining the Regeneration Conditions

WAVE allows to specify some regeneration conditions in the Regeneration Condition Window, as shown in Figure 172. The following conditions can be specified for both cation and anion resins:

- Regenerant chemicals
- Regeneration temperature
- Number of regeneration steps, concentration and dose fraction
- Source of service water (Feed water, Treated water, Other water)

Select the required regenerants and specify the dosing temperature. It is also possible to dose the regenerant in a maximum of 3 different steps at three different concentrations, however the sum of all different dose fractions must be 100%. For the cation resin using sulfuric acid, WAVE will recommend regeneration conditions based on the feed water calcium to total cations ratio.

Finally, select the quality of service water for the backwash and the regeneration. The water quality selected for the regeneration is the water quality that will be used for injection and displacement rinse. For refill and fast rinse steps, feed water will be used.

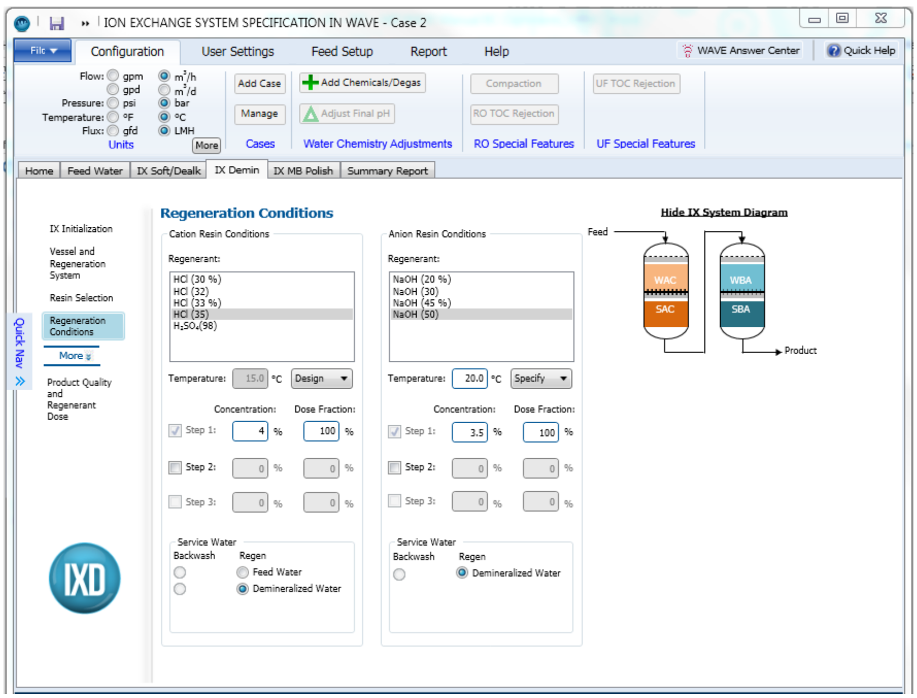

Figure 172. Regeneration Conditions

Notes:

- In WAVE, the user must select a regenerant for cation/anion resins. The regenerant is selected from the list of default chemicals and other chemicals defined by the user (as described in Chemical Library).
- Based on the selected process, default values for regenerant concentration are recommended.
- When required (i.e., Brackish Softening with a WAC), WAVE will display the options for Step 1 (regeneration with acid) and Step 2 (resin conversion to Na form), as shown in Figure 173.
- WAVE allows 2 different options for the dosing temperature.
    1. Design: the dosing temperature will be the same as the one specified for the feed water in the Feed Water Tab
    2. Specify: when this option is selected, WAVE allows the user to specify the dosing temperature.
- WAVE will deactivate the water quality options for backwash according to the Regeneration System previously selected.
- In IX Condensate Polishing the only available source of service water is Other Water.

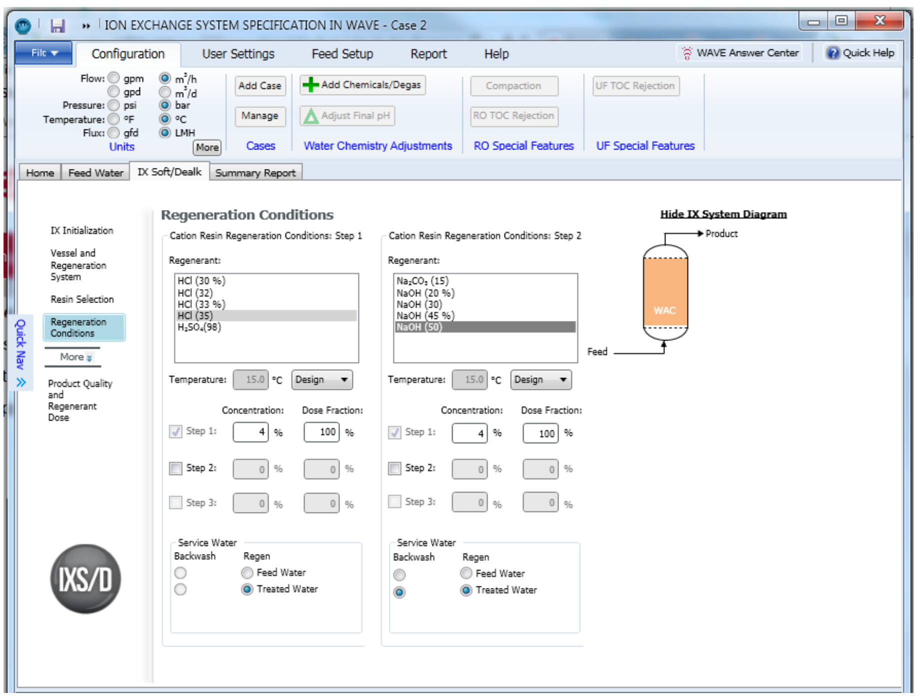

Figure 173. Regeneration Conditions for Brackish Softening with a WAC (H/Na)

5.1.9 Defining the Advanced Regeneration Conditions

WAVE makes possible specification of additional regeneration conditions in the Advanced Regeneration Window, as shown below in Figure 174. The Advanced Regeneration Window is hidden by default but can be displayed by clicking on the 'More' button as shown in below in Figure 174. The following variables can be specified in WAVE: Backwash Frequency, Backwash Expansion, Backwash Duration, Compaction Duration, Regeneration Specific Velocity, SBA/SAC Regeneration Flow Ratio, Regeneration Hold-Down Factor, Displacement Rinse Flow, Displacement Rinse Volume, Fast Rinse Volume, Fast Rinse Recycle, and Settling Duration.

- **Backwash Frequency** - Number of cycles between 2 consecutive backwashes. This option is displayed as **MB Separation Backwash Frequency** only for the Mixed Bed (IXMB and IXCP Process).
- **Backwash Expansion** - Percentage expansion for the ion exchange bed. This option is displayed as **MB Separation Backwash Expansion** only for the Mixed Bed (IXMB and IXCP Process).
- **Backwash Duration - Time specified for backwash.** This option is displayed as **MB Separation Backwash Duration** only for the Mixed Bed (IXMB and IXCP Process).
- **Compaction Duration**
- **Regeneration Specific Velocity**: WAVE allows the user to specify the specific velocity for the different regenerants. Note: For the IXMB Process:
  - for internal regeneration the user is able to modify the regeneration specific velocity for cation resin. Anion specific velocity will be calculated based on the specific cation velocity, SBA/SAC regeneration flow ratio and resin volume. Anion linear velocity (m/h) = cation linear velocity (m/h) x SBA/SAC regen flow ratio.
  - for external regeneration the user is able to modify the regeneration specific velocity for both cation and anion resin.
- **SBA/SAC Regeneration Flow Ratio** (this variable is only displayed for IXMB and IXCP Process)
- **Regeneration Hold-Down Factor**
- **Displacement Rinse Flow**
  - @ regeneration flow: the same flow used during regeneration (regenerant + dilution water) will be used for displacement rinse.
  - @ dilution flow: the dilution water flow used during regeneration will be used for displacement rinse.

  Note: The dilution flow will always be smaller than the regeneration flow.
- **Displacement Rinse Volume**: After the specified quantity of regenerant has been introduced, the regenerant chemical injection is stopped and only the dilution water continues to be injected to displace the regenerant.
- **Fast Rinse Volume**: Fast final rinse is carried out at service flow rate and direction until the required effluent quality is obtained
- **Fast Rinse Recycle**: WAVE gives the option to rinse to waste or to recycle the fast rinse.
  - None: Rinse to waste.
  - After 3 minutes: 3 min of rinse to waste prior to recycle.
  - Full: All the water used during the Fast Rinse step will be recycled.

- Settling Duration

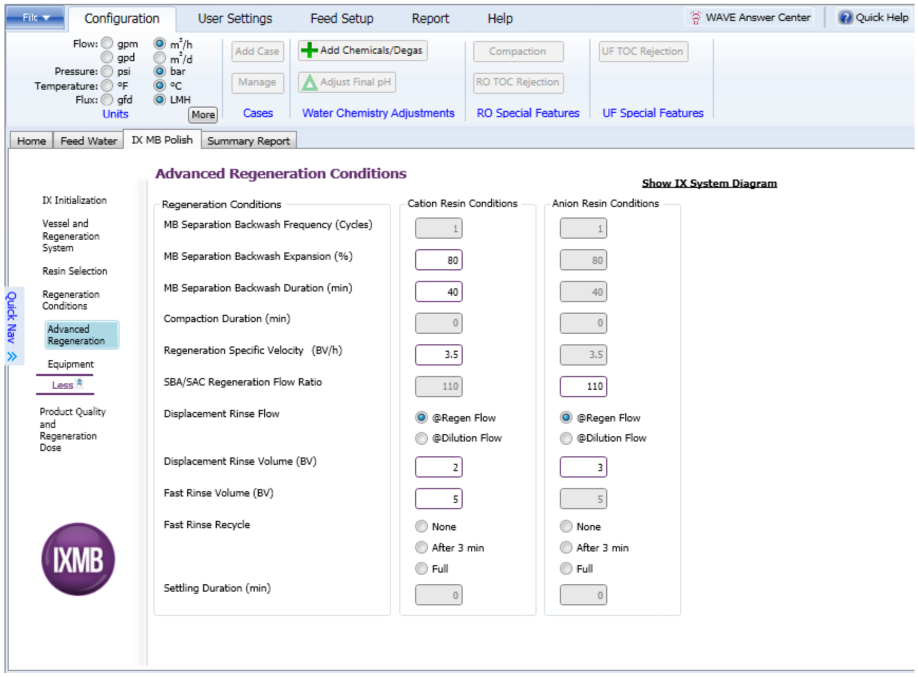

Figure 174. Advanced Regeneration Conditions

5.1.10 Defining the Equipment

WAVE allows the user to specify additional information regarding equipment settings in the Equipment Window (as shown in Figure 175). The following parameters can be specified:

1. Typical pressure drop of internal distributors
2. Typical pressure drop of external piping
3. Effluent pressure
4. Bulk chemical storage tank temperature

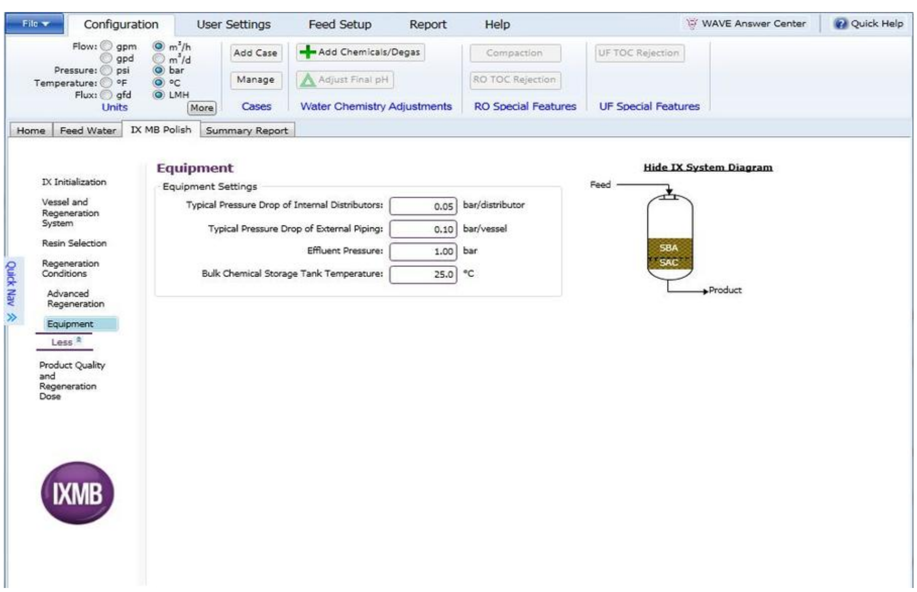

Figure 175. Equipment Settings

In the case of IXMB and IXCP processes, if external regeneration is selected, WAVE will display the External Regeneration and Other Equipment Window instead of the Equipment Window and, in addition to the Equipment Setting options, the External Regeneration Equipment Setting options (i.e. Backwash Tower Diameter, SAC Regeneration Vessel Diameter, and SBA Regeneration Vessel Diameter) will be displayed (see Figure 176).

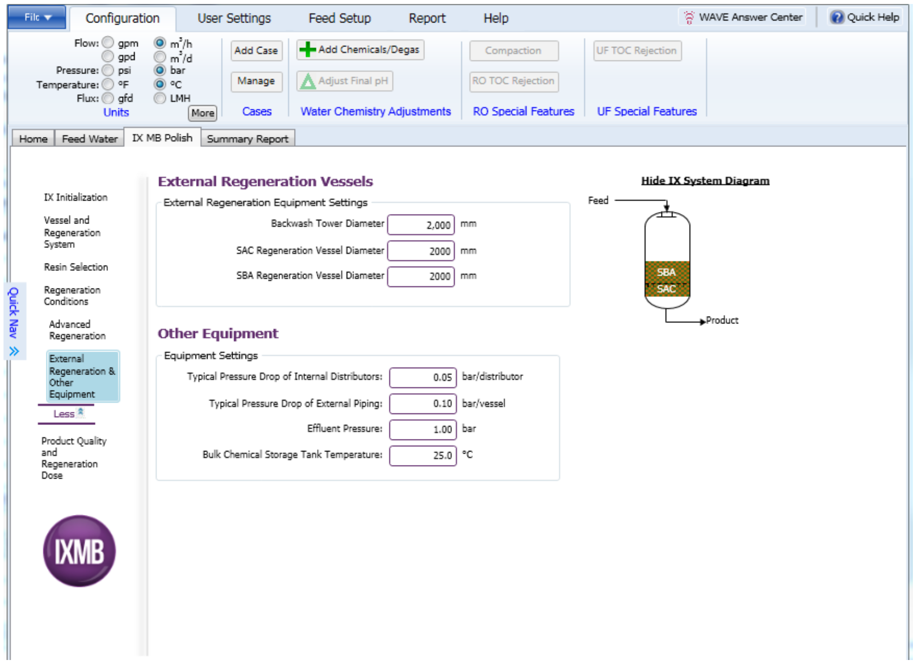

Figure 176. External regeneration equipment settings (option available for the IXMB and IXCP processes with external regeneration)

5.1.11 Defining the Product Quality and Regeneration Dose

The Product Quality and Regenerant Dose Window allows the WAVE user to specify (as shown in Figure 177):

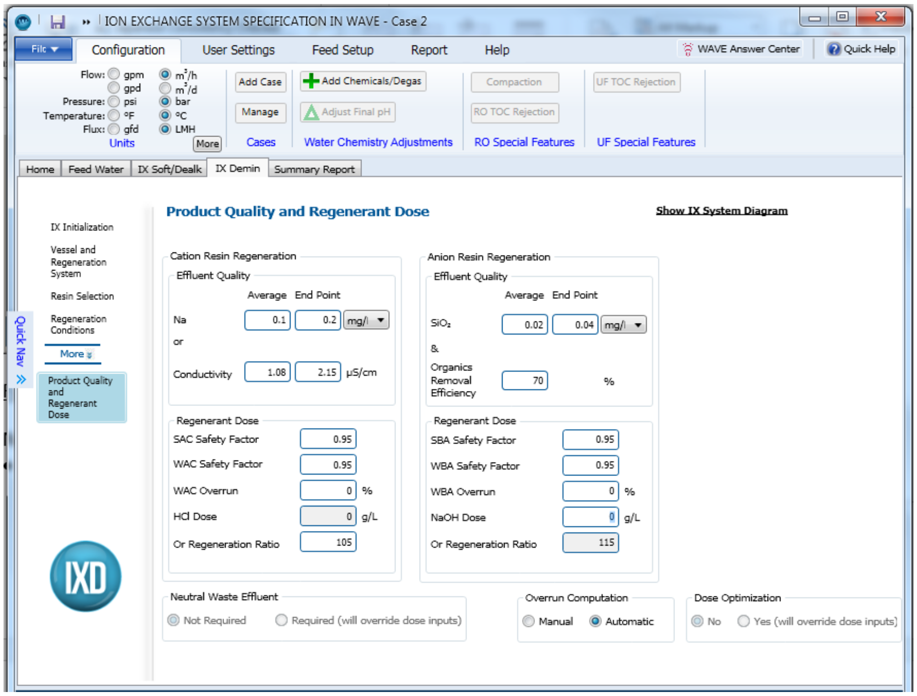

Figure 177. Product Quality and Regeneration Dose Selection

The Effluent Quality

WAVE allows the user to specify the desired quality of the produced water. Depending on the IX process the user will be asked to specify:

IX Process	Effluent Quality
Softening	• Average hardness leakage • Hardness end point
Dealkalization	• Average alkalinity leakage • Alkalinity end point
Demineralization	For Cation resin the effluent quality parameters can be specified in two ways: • Average sodium leakage (this would be the expected average conductivity at the outlet of the anion vessel) • Sodium end point *or* • Average conductivity value • Conductivity end point Note: Only one of the options above should be specified and the other one will be automatically calculated. For Anion resin specify the effluent quality parameter as • Average silica leakage • Silica end point
Mixed Bed	For Cation resin the effluent quality parameters can be specified in two ways: • Average sodium leakage • Sodium end point *or* • Average conductivity value (this would be the expected average conductivity at the outlet of the anion vessel) • Conductivity end point Note: Only one of the options above should be specified and the other one will be automatically calculated. For Anion resin specify the following effluent quality parameters • Average silica leakage • Silica end point and • Organics removal efficiency: introduce the expected percentage of organics removal.
Condensate Polishing	For Cation resin the effluent quality parameters can be specified in two ways: • Average NH_4^+/NH_3 leakage • NH_4^+/NH_3 end point *or* • Average conductivity value (this would be the expected average conductivity at the outlet of the anion vessel) • Conductivity end point Note: Only one of the options above should be specified and the other one will be automatically calculated. For Anion resin specify the effluent quality parameter as • Average silica leakage • Silica end point

Notes:

- Average leakage referes to the expected average leakage during the operation cycle
- End point refers to the point when the system will stop operating and start regeneration

The Regenerant Dose

The Regenerant Dose section allows the user to specify the following parameters for the cation and the anion resins (as well as for the different regeneration steps when appropriate, i.e. Brackish softening with WAC (H/Na)):

- **Safety Factor:** the lower the value, the higher the safety is being taken. The higher the value, the smaller the safety is being taken.

  In this screen the user's input would be the minimum safety factor accepted. The final safety factor used will be based on the following: Effective Operating Capacity / Theoretical Operating Capacity (appears in the report as Operating Capacity).

  Effective operating capacity is the total ionic load divided by total resin volume. As resin volume can be adjusted for resin packaging sizes for example, the effective operating capacity will be equal or lower than theoretical operating capacity. Therefore, final safety factor value will be equal or smaller than user's safety value input (meaning that always the same or more safety will be finally taken).

  Note: If the user manually enters a volume on the Final Parameter Adjustments screen (see Section 7.13) less than what WAVE computed, it is possible to get an actual safety factor greater than the user's input. In that case, WAVE will include a warning in the project report.

- **WAC Overrun/WBA Overrun**: amount of ionic load carried over from the WAC to the SAC resin or from the WBA to the SBA when the "Manual" option is selected in the Overrun Computation box (see Section 7.11.4 for more details).
- **Regenerant Dose**: mass of regenerant 100% pure per volume of SAC (or SBA) resin in reference form.
- **Regeneration Ratio**: level of regeneration expressed in percentage of the WAC (or WBA) operating capacity (e.g. 115 % Regeneration Ratio on a WAC means that a quantity of H+ ions equal to 1.15 time the quantity of ions fixed on the resin will be used).

Neutral Water Effluent

WAVE provides the option of neutralizing the IX waste stream. This can be activated by clicking on “Required (will over-ride dose inputs)” option in the Neutral Waste Effluent box (see Figure 178). As stated, WAVE would over-ride regenerant dose values to achieve a pH-neutral waste stream.

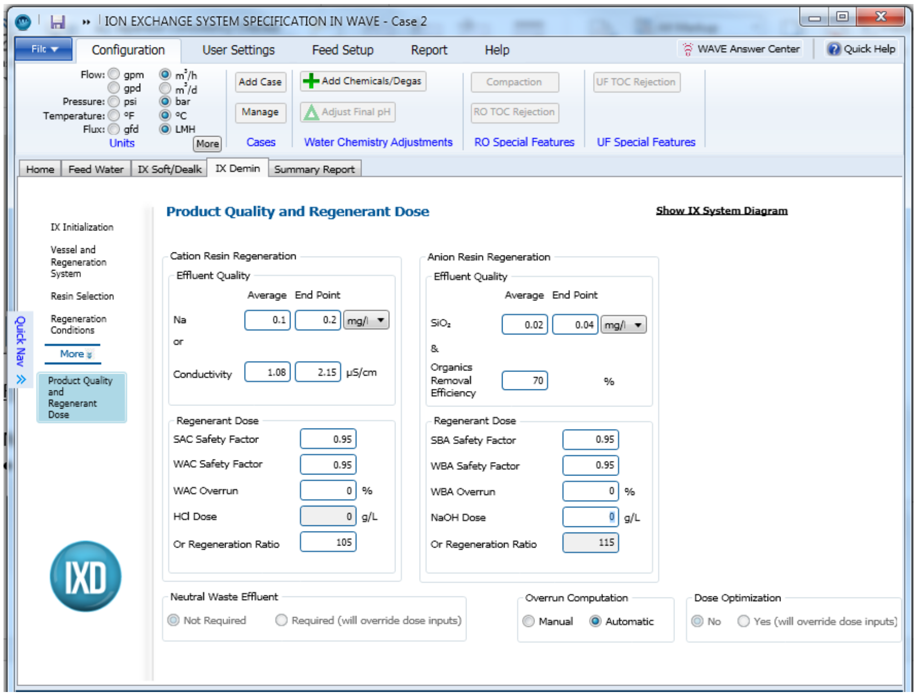

Figure 178. Product Quality and Regeneration Dose Window

Notes:

- Neutral Waste Effluent option is only available for IX processes where a cation and anion are involved.
- If the Dose Optimization option is selected (see Dose Optimization), the Neutral Waste Effluent option will not be available.
- In demineralization systems involving a weak/strong couple, the Neutral Waste Effluent option will be available only if the Regenerant Dose is specified as Dose but not as Regeneration Ratio.

Overrun Computation

For WAC-SAC or WBA-SBA resin couples in demineralizers, WAVE will calculate the overrun to increase the load on the strong resin by increasing the ionic leakage from the weak resin. Depending on the options previously specified, WAVE will adjust the overrun in order that:

- The total quantity of chemical meets minimum recommended stoichiometric ratio.

  When the "Length of Operating Cycles" and the regenerant "Dose" are specified, respectively, in the IX Initialization Window and in the Product Quality and Regenerant Dose Window, WAVE calculates the amount of regenerant required based on strong resin. However, most of the ions are picked up by the weak resin. If there is not enough regenerant left over for the weak resin, then WAVE 'over-runs' to increase the load on the strong resin and the total quantity of regenerant needed. WAVE adjusts the overrun so that there is sufficient chemical to ensure that both resins are well regenerated (which also gives the best match of capacity and hydraulics).

- The total volume of resin (weak + strong combination) is minimized.

  When the "Length of Operating Cycles" and the "Regeneration Ratio" are specified, respectively, in the IX Initialization Window and in the Product Quality and Regenerant Dose Window, the amount of regenerant is given by the ionic load and the Regeneration Ratio. In this case, WAVE adjusts the overrun in order to minimize the total volume (weak + strong) resin.

- Weak resin potential run time and strong resin potential run time are comparable.

  When the Length of Operating Cycle is to be determined (e.g. Evaluating Existing Plant mode), WAVE adjusts the overrun so that weak resin potential run time and strong resin potential run time are comparable.

WAVE also provides the user with the option to input the amount of over-run by clicking on the radio button for "Manual" in the Overrun Computation box.

Dose Optimization

WAVE allows the user to optimize the design in two different ways

- Optimize the chemical dosage. WAVE will calculate the optimum regenerant concentration to meet the target quality and it will override user's inputs.

  If Dose Optimization is not selected, a warning will appear in the report if the selected design does not reach the target quality. If regenerant is overdosed, the product water quality in the report will be higher than required and the dose can be manually adjusted.

- Optimize design to minimize chemical consumption while meeting run length, leakage, stoichiometry, and hydraulic constraints.

5.1.12 Existing Plant Description

If "Evaluate Existing Plant" or "Retrofit Plant to UPCORE ™" options are selected during the description of the Modeling Objective (see The Modeling Objective), an eighth button called Existing Plant Description will be added to the left-hand navigation area (see Figure 179).

The Existing Plant Description Window allows the user to specify the following parameters (as shown in Figure 179):

1. Resin Volumes
2. Vessel Diameter
3. Inert Bed Height (only available for some Regeneration Systems)
4. Vessel Cylindrical Height
5. Vessel Wall Thickness
6. Resin Packaging Size

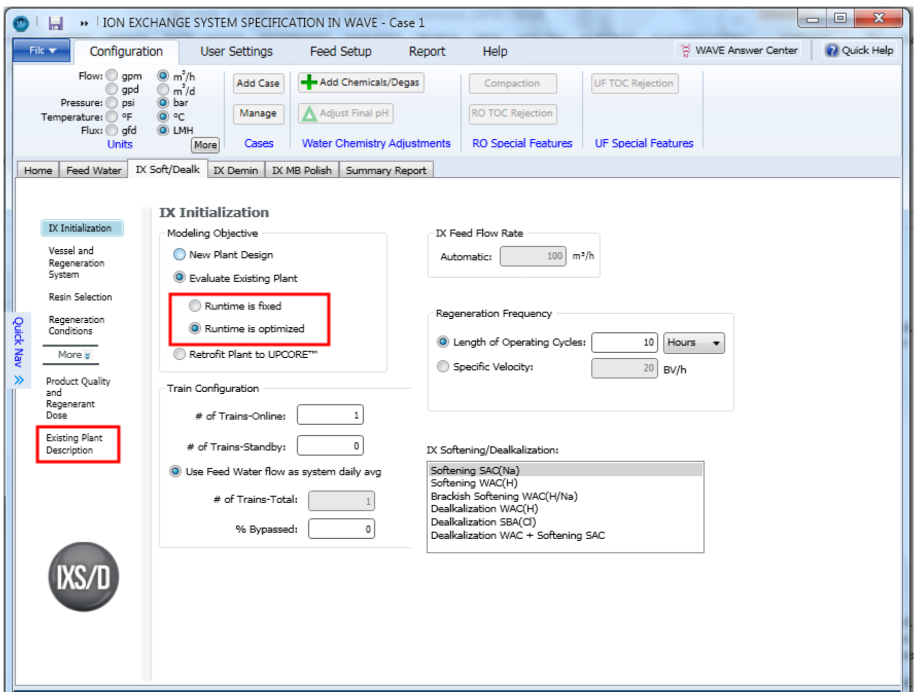

Figure 179. Existing Plant Description

Notes:

- At the bottom of the Existing Plant Description window, only the option "Use Vessel Geometry and Resin Volume values" is available.
- If the Vessel Height input is inconsistent with the Resin Volume and Vessel Diameter inputs, WAVE will issue a warning indicating the minimum required Vessel Height, as shown in Figure 180.

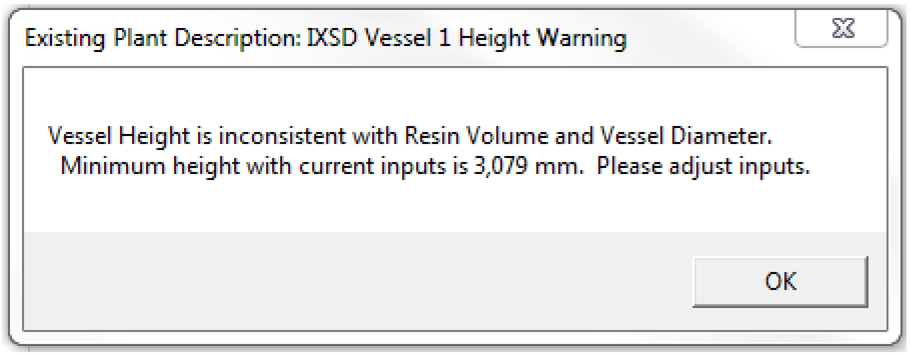

Figure 180. Existing Plant Description. Height Warning

5.1.13 Final Parameter Adjustments

After running the summary report (see Section 8.1), if the WAVE user goes back to any of the IX Process screens (IX Soft/Dealk, IX Demin or IX MB Polish), the option of Final Parameter Adjustments will appear on the left (see Figure 181).

In this screen it is possible to fine tune the following parameters:

1. Resin volumes
2. Vessel diameter
3. Vessel cylindrical height
4. Vessel wall thickness
5. Resin packaging size: this option will override the selected resin packaging size selected in the Resin Selection screen.

Finally, at the bottom of this screen one of the three following options should be selected:

- Use Vessel Geometry and Resin Volume values: WAVE will use the resin volume and vessel diameter specified in this screen.
- Use Vessel Geometry values, ignore Resin Volume values: WAVE will use the vessel volume geometry specified and fill it with resins. The volume of resins will not be adjusted to cycle length but to vessel dimensions.
- Ignore Vessel Geometry and Resin Volume values: WAVE will ignore all resin volumes that have been introduced and vessel sizing and will recalculate the suggested resin volume and size according user's design inputs (as it does in the first run).

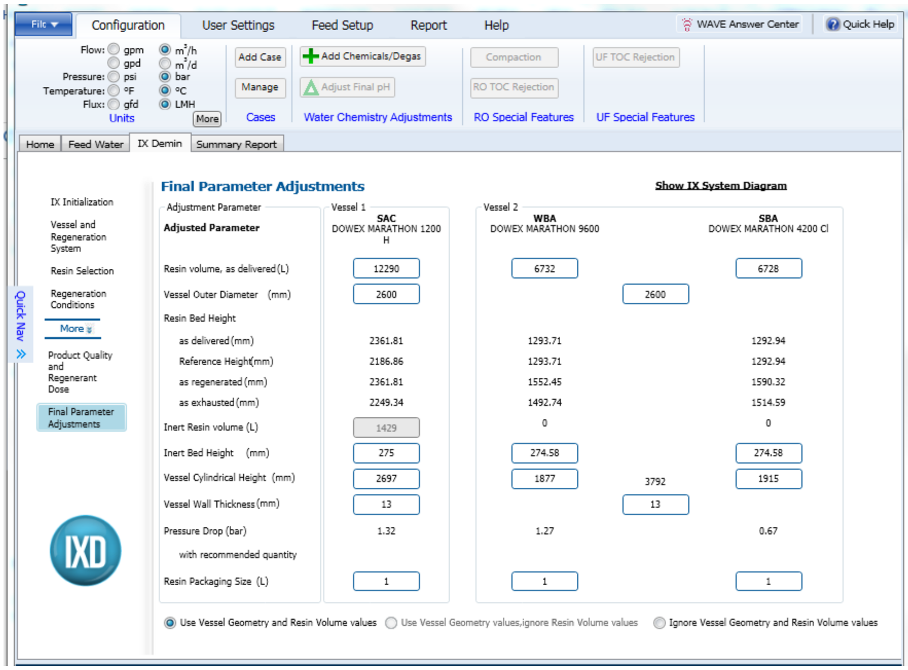

Figure 181. Final Parameters Adjustment Window

5.2 Ion Exchange Final Calculation and Report Generation

Once the system design inputs are available in WAVE, WAVE can be run to model the system. The details of the following actions that can be performed to generate, modify and handle the reports are described below:

5.2.1 Generating and Understanding Summary Report

Once all the required inputs are in place in the IX Processes Tab (IXS/D, IX Demin and/or IXMB) , the IX system "Summary Report" can be generated as shown in Figure 182.

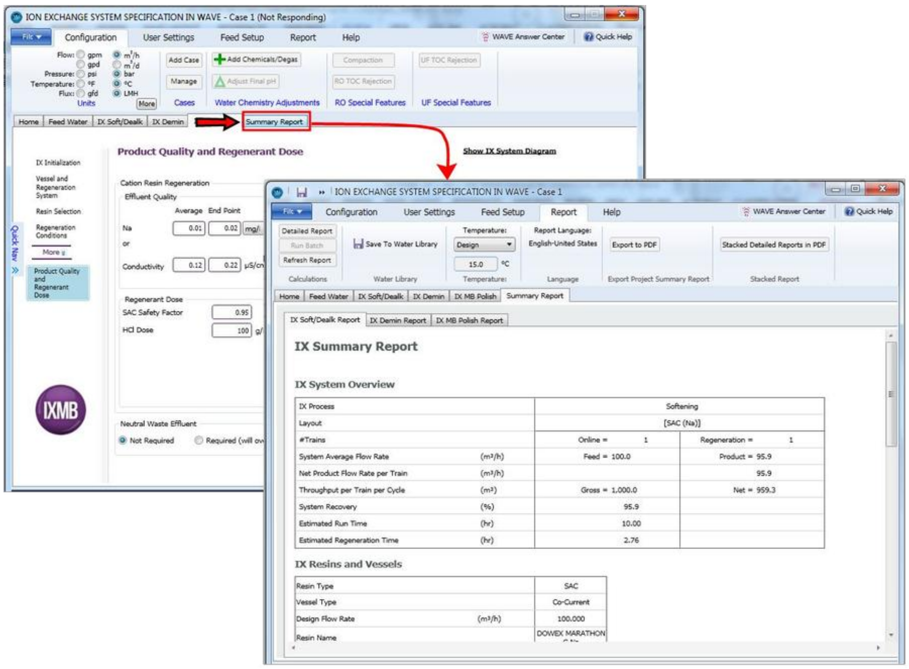

Figure 182. WAVE Summary Report and Detailed Report generation for IX

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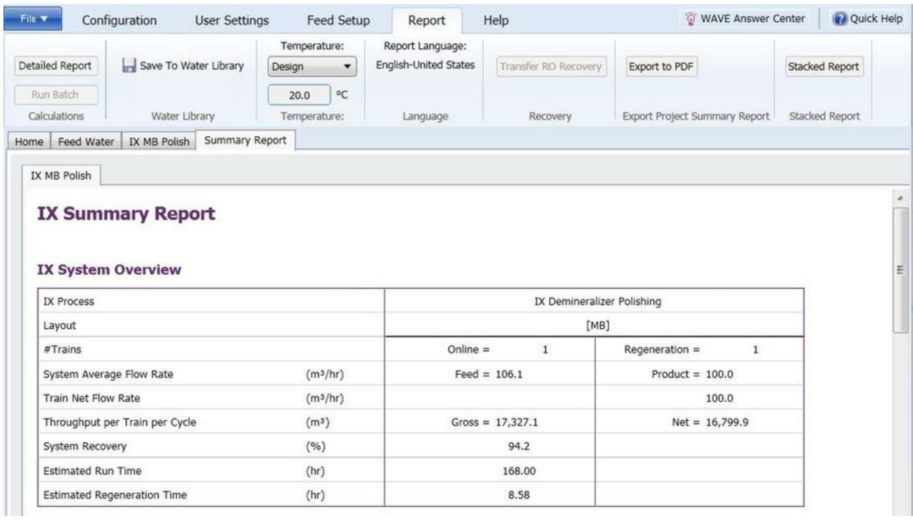
January 2020

In addition to the IX System Overview, the Summary Report includes 4 tables summarizing the key plant details, operating parameters and performance (results may vary depending on specific operating conditions):

1. IX System Overview
2. IX Resins and Vessels
3. IX Water Quality
4. IX Design Warnings



IX Resins and Vessels

Resin Type		SAC	SBA
Design Flow Rate	(m^3/hr)	103.138	103.138
Resin Name		AMBERJET 1000 H	AMBERJET 4200 Cl
Ionic Form (Delivered)		H	Cl
Ionic Form (Reference)		Na	Cl
Resin Volume (Reference Form)	(L)	28,925	57,732
Total Bed Resin Volume	(L)	86657	
Fraction of Bed	(%)	33.4	66.6
Regeneration System		MB, Internal Regen	MB, Internal Regen
Regenerant		HCl	NaOH
Regeneration Dose	(g/L)	100.0	100.0
Regeneration Ratio	(%)	286	315
Operating Capacity	(eq/L)	1.01	0.54
Effective Operating Capacity	(eq/L)	0.96	0.51
Silica Loading	(g/L SiO_2)		0.00
	(g NaOH/g SiO_2)		NaN
Vessel Outside Diameter	(mm)	1,500	1,500
Bed Depth (Delivered)	(mm)	18,495	33,559
Total Bed Depth	(mm)	52054	
Bed Depth (Reference)	(mm)	16,814	33,559
Total Bed Depth	(mm)	50373	
Freeboard	(mm)	40,298	40,298
Specific Velocity	(BV/hr)	3.57	1.79
Total Bed Specific Velocity	(BV/hr)	1.19	1.19
Linear Velocity	(m/hr)	59.95	59.95
Estimated Pressure Drop @ 20.0 °C	(bar)	11.55	22.42
Total Pressure Drop @ 20.0 °C	(bar)	33.97	

Computation performed without adjustment.

IX Water Quality

		Feed	Required Average	Required EndPoint	Estimated Average
pH		7.20	-	-	7.29
Conductivity	(µS/cm)	171.19	0.12	0.22	0.058
Na	(mg/L)	13.832	0.010	0.020	0.002
SiO_2	(mg/L)	0.000	0.010	0.020	< 0.001

IX Design Warnings

Design Warning		Limit	Estimate	Resin
Loading Specific Velocity < Min	(BV/hr)	15.00	1.19	AMBERJET 1000 H AMBERJET 4200 Cl
Regeneration Linear Velocity > Max	(m/hr)	20.00	58.85	AMBERJET 1000 H
Resin Height > Max	(mm)	1,500	16,814	AMBERJET 1000 H
Pressure Drop > Max	(bar)	1.00	33.97	AMBERJET 1000 H AMBERJET 4200 Cl
Regeneration Specific Velocity < Min	(BV/hr)	2.00	1.93	AMBERJET 4200 Cl
Regeneration Linear Velocity > Max	(m/hr)	20.00	64.73	AMBERJET 4200 Cl
Resin Height > Max	(mm)	1,500	33,559	AMBERJET 4200 Cl

5.2.2 Generating and Understanding the IX Detailed Report

IX Detailed Report can be generated as shown below:

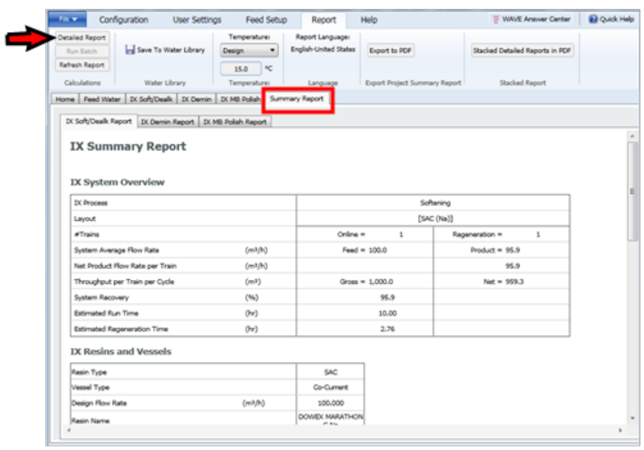


Figure 183. Generation of Detailed Reports in WAVE

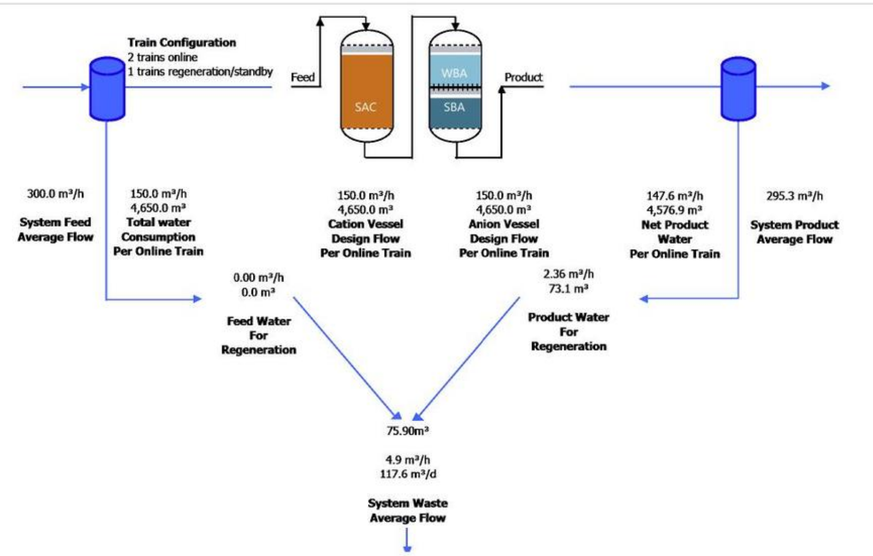
Detailed Report Components are shown below (Results may vary depending on specific operating conditions).

1. IX System Overview (including Flow Diagram)
2. IX Resins and Vessels
3. IW Water Quality
4. IX Design Warnings
5. IX Resins
6. IX Vessels
7. IX Regeneration (including Chemical Consumption, Service Water Consumption, Regeneration Efficiency and Regeneration Protocol)
8. IX Water Composition
9. IX Utility and Chemical Costs (including Service Water and Electricity)

IX Detailed Report

IX System Overview

IX Process		Demineralization				
Layout		[SAC] - [WBA | SBA]				
#Trains		Online =	2	Regeneration =	1	
System Average Flow Rate	(m^3/h)	Feed =	300.0	Product =	295.3	
Net Product Flow Rate per Train	(m^3/h)				147.6	
Throughput per Train per Cycle	(m^3)	Gross =	4,650.0	Net =	4,576.9	
System Recovery	(%)	98.4				
Estimated Run Time	(hr)	31.00				
Estimated Regeneration Time	(hr)	1.53				



IX Resins and Vessels

Resin Type		SAC	WBA	SBA
Vessel Type		AMBERPACK	AMBERPACK	AMBERPACK
Design Flow Rate	(m^3/h)	179.999	179.999	179.999
Resin Name		DOWEX MARATHON 1200 H	DOWEX MARATHON 9600	DOWEX MARATHON 4200 Cl
Ionic Form (Delivered)		H	FB	Cl
Ionic Form (Reference)		Na	FB	Cl
Resin Volume (Reference Form)	(L)	9,781	6,465	5,380
Potential Runtime	(hr)	31.00	31.00	31.01
Potential Throughput	(m^3)	5,579.415	5,579.584	5,582.298
Operating Capacity	(eq/L)	0.96	1.16	0.75
Effective Operating Capacity	(eq/L)	0.91	1.10	0.72
Ionic Load	(eq)	8,891	7,100	3,851
Organic (TOC) Loading	(g/L TOC)		0.85	0.30
Silica Loading	(g/L SiO_2)		0.00	3.11
	(g NaOH/g SiO_2)			38.66
Silica Loading Limit	(g/L SiO_2)		0.00	12.02
TSS Loading	(kg/m^2)	0.19	0.00	0.00
Regenerant		H_2SO_4	NaOH	NaOH
Regeneration Dose	(g/L)	70.0		120.3
Overrun	(%)		10	
Regeneration Ratio	(%)	157	130	233
Regeneration Ratio (Resin Couple)	(%)		115	
Excess Regenerant	(eq)	5,070	2,125	
Vessel Outside Diameter	(mm)	2,400	2,400	2,400
Bed Depth (Delivered)	(mm)	2,386	1,461	1,215
Bed Depth (Reference)	(mm)	2,210	1,461	1,215
Freeboard	(mm)	230	50	50
Specific Velocity	(BV/hr)	18.40	27.84	33.46
Linear Velocity	(m/h)	40.66	40.66	40.66
Estimated Pressure Drop @ 15.0 °C	(bar)	1.31	1.39	0.61
Capacity Safety Factor		0.950	0.950	0.950

Computation performed without adjustment.

Flow Rates				
		System Average	Online Train per Cycle	
		Flow Rate	Flow Rate	Volume
System Feed	(m^3/h)	300.0		
Bypass	(m^3/h)	0.0		
Total Water Consumption	(m^3/h)	300.0	150.0	4,650.0 m^3
Total Regeneration Water	(m^3/h)	-4.7	-2.4	-73.1 m^3
Net Product Water	(m^3/h)	295.3	147.6	4,576.9 m^3
Bypass	(m^3/h)	0.0		
System Product	(m^3/h)	295.3		
IX Recovery		98.43 %		
System Overall Recovery (Including Bypass)		98.43 %		

Cycle Times		
		Overall System
Regeneration Cycle	(hr)	1.53
Loading Cycle	(hr)	31.00
Complete Cycle	(hr)	32.53
Cycles per Online Train per Day		0.77

IX Water Quality

		Feed	Required Average	Required EndPoint	Estimated Average
pH @ 10.0 °C		6.30	-	-	8.93
Conductivity @ 25 °C	(µS/cm)	192.15	2.00	4.00	0.65
Na	(mg/L)	25.560	0.186	0.372	0.056
SiO_2	(µg/L)	3000	20	40	2

IX Design Warnings

None

IX Resins

IX Resin Type, Volume, Height, Capacity				
Resin #		1	2	3
Name		DOWEX MARATHON 1200 H	DOWEX MARATHON 9600	DOWEX MARATHON 4200 Cl
Ionic Form Delivered		H	FB	Cl
Volume				
Delivered	(L)	9,111	5,307	4,874
Reference	(L)	8,436	5,307	4,874
Exhausted	(L)	8,677	6,123	5,710
Regenerated	(L)	9,111	6,368	5,995
Height				
Delivered	(mm)	2,243	1,307	1,200
Reference	(mm)	2,077	1,307	1,200
Exhausted	(mm)	2,137	1,508	1,406
Regenerated	(mm)	2,243	1,568	1,476
Inert Resin				
Resin		UPCORE IF-62	UPCORE IF-62	UPCORE IF-62
Volume	(L)	1,067	1,067	1,067
Height	(mm)	263	263	263
Capacity Summary				
Safety Factor		0.950	0.950	0.941
Operating Capacity	(eq/L)	0.92	1.14	0.73
Effective Operating Capacity	(eq/L)	0.88	1.09	0.69
Organic (TOC) Loading	(g/L TOC)		0.859	0.280
Silica Loading	(g/L SiO_2)		0.000	2.862
	(g NaOH / g SiO_2)			38.64
TSS Loading	(kg/m²)	0.17	0.00	0.00

IX Vessels

IX Vessel Size, Hydraulics, and Pressure Drop			
Vessel #		**1**	**2**
Vessel Type		Single Resin	2 Chamber
Regeneration System		UPCORE	UPCORE
Diameter:			
Outside	(mm)	2,300	2,300
Inside	(mm)	2,274	2,274
Internal Area	(m^2)	4.061	4.061
Compartment 1			
Resin		DOWEX MARATHON 1200 H	DOWEX MARATHON 9600
Resin Maximum Height	(mm)	2,243	1,568
Specific Velocity	(BV/hr)	17.78	28.26
Linear Velocity	(m/h)	36.93	36.93
Resin ΔP: Loading	(bar)	1.27	1.30
Compartment Wall Height	(mm)	2,564	1,881
Freeboard	(mm)	58	50
Compartment 2			
Resin			DOWEX MARATHON 4200 Cl
Resin Maximum Height	(mm)		1,476
Specific Velocity	(BV/hr)		30.78
Linear Velocity	(m/h)		36.93
Resin ΔP: Loading	(bar)		0.63
Compartment Wall Height	(mm)		1,789
Freeboard	(mm)		50
Combined Compartment Wall Height	(mm)		3,670
Vessel ΔP	(bar)	1.47	2.18
System ΔP	(bar)	3.65	
Estimated Feed Pressure	(bar)	4.65	

IX Regeneration

IX Chemical Consumption			
Regeneration Protocol		1	2
Regenerant		H_2SO_4	NaOH
Bulk Concentration	(%)	98	20
Unit Cost	(€/kg)	0.06	0.16
Regeneration Temperature	(°C)	10.0	33.0
Dose			
Weight Basis	(g/L)	70.0	110.6
Stoichiometric Basis	(%)	0.0	115.0
Over-Run Factor	(%)	0.0	15.0
Consumption			
per Regeneration			
@ Bulk Concentration	(kg)	603	2,694
@ 100 % Basis	(kg)	591	539
per Day			
@ Bulk Concentration	(kg/day)	933.0	4,171.4
@ 100 % Basis	(kg/day)	914.3	834.3
Daily Cost	(€/day)	52.25	667.43
Total Chemical Cost	(€/day)	721.33	

IX Service Water Consumption				
		Decationized	Feed	Product
Volume per Regeneration	(m³/regen)	0.0	0.0	73.1
Volume per Day	(m³/day)	0.0	0.0	113.2

IX Regeneration Efficiency				
Individual Resin		1	2	3
Regen. Requirements	(eq)	7,409	5,764	5,950
Total Regenerant	(eq)	12,041	7,520	13,470
Equivalent Ratio		163 %	130 %	226 %
Combined Resins				
Regen. Requirements	(eq)	7,409	11,714	
Total Regenerant	(eq)	12,041	13,470	
Equivalent Ratio		162.52 %	114.99 %	

IX Regeneration Protocol								
	Conc	Flow Rate		Linear Velocity	Time	Volume		Water Source
	(%)	(m^3/h)	(BV/hr)	(m/h)	(min)	(m^3)	(BV)	
Protocol 1								
SAC Resin								
Compaction		137.05	16.25	33.75	3.00	6.85	0.81	Demineralized Water
Injection #1	2.50	36.63	4.34	9.02	19.03	11.62	1.38	Demineralized Water
Injection #2	5.00	37.00	4.39	9.11	9.27	5.72	0.68	Demineralized Water
Displacement Rinse		36.29	4.30	8.94	27.90	16.87	2.00	Demineralized Water
Settling					10.00			
Fast Rinse Recycle		150.00	17.78	36.93	22.34	55.85	6.62	Recycled water
Total					91.54	96.91		
Protocol 2								
WBA Resin								
Compaction		110.87	20.89	27.30	3.00	5.54	1.05	Demineralized Water
Injection #1	4.00	38.17	7.19	9.40	20.29	12.91	2.43	Demineralized Water
Displacement Rinse		31.85	6.00	7.84	29.99	15.92	3.00	Demineralized Water
Settling					10.00			
Fast Rinse Recycle		150.00	28.26	36.93	22.34	55.85	10.52	Recycled water
SBA Resin								
Compaction		110.87	22.75	27.30	3.00	5.54	1.14	Demineralized Water
Injection #1	4.00	38.17	7.83	9.40	20.29	12.91	2.65	Demineralized Water
Displacement Rinse		31.85	6.54	7.84	29.99	15.92	3.27	Demineralized Water
Settling					10.00			
Fast Rinse Recycle		150.00	30.78	36.93	22.34	55.85	11.46	Recycled water
Total					85.62	90.22		

Fast Rinse with full recycle

		Energy (kW-hr)		
Operation	**Power (kW)**	**per Regen**	**per Day**	**Cost (€/d)**
Feed Pump	52.7		1,263.6	118.85
Regeneration Protocol 1				
Backwash & Compaction Pump	7.0	0.3		
Regeneration Pump	0.7	0.6		
Fast Rinse Pump	8.3	3.1		
Heating	0.0	0.0		
Regeneration 1 Total	8.3	4.1	6.3	0.59
Regeneration Protocol 2				
Backwash & Compaction Pump	6.9	0.3		
Regeneration Pump	0.8	0.6		
Fast Rinse Pump	12.3	4.6		
Heating	1,016.1	0.0		
Regeneration 2 Total	1,017.0	5.5	8.5	0.8
Total Regeneration			14.8	1.39
Total System			1,278.5	120.25

IX Water Composition

Ionic Concentration and Other Attributes				
Species		IX Feed	IX Product (Effluent)	IX System Waste
NH_3/NH_4^+ Total	(meq/L)	0.00	0.00	0
K^+	(meq/L)	0.02	0.00	2
Na^+	(meq/L)	1.11	0.00	255
Mg^{+2}	(meq/L)	0.16	0.00	10
Ca^{+2}	(meq/L)	0.30	0.00	19
Sr^{+2}	(meq/L)	0.00	0.00	0
Ba^{+2}	(meq/L)	0.00	0.00	0
Total Exchangeable Cations	(meq/L)	1.60	0.00	286
CO_3^{-2}	(meq/L)	0.00	0.00	0
HCO_3^-	(meq/L)	0.24	0.00	15
CO_2	(mg/L)	13.93	0.00	887
NO_3^-	(meq/L)	0.03	0.00	2
Cl^-	(meq/L)	0.57	0.00	36
F^-	(meq/L)	0.00	0.00	0
SO_4^{-2}	(meq/L)	0.76	0.00	213
SiO_2 Total	(mg/L)	3.00	0.00	191
B Total	(mg/L)	0.00	0.00	0
Total Exchangeable Anions	(meq/L)	1.96	0.00	290
TDS	(g/L)	0.13	0.00	20.41
pH @ 10.0 °C		6.30	8.93	7.50
Hardness	(meq/L)	0.46	0.00	29.27
Total Alkalinity	(meq/L)	0.24	0.00	34.65
Organics (TOC)	(mg/L TOC)	1.40	0.13	81.19
Conductivity @ 25 °C	(µS/cm)	192.15	0.65	23,618.63
Temperature	(°C)	10.0	10.0	10.0

IX Utility and Chemical Costs

Service Water

	Average Flowrate (m^3/h)	Unit Cost (€/m^3)	Cost (€/h)	Cost (€/d)
Non-Product Feed Water	4.71	0.15	0.71	17.03
Waste Water Disposal	4.87	0.73	3.57	85.69
Total Service Water Cost			4.28	102.72

Electricity

Peak Power	(kW)	1,077.94
Energy	(kWh/d)	1,278.47
Electricity Unit Cost	(€/kWh)	0.09
Electricity Cost	(€/d)	120.25
Specific Energy	(kWh/m^3)	0.180

Utility and Chemical Cost	(€/d)	944.29
Specific Water Cost	(€/m^3)	0.133

5.2.3 Modification of System Design after Calculation

After the first simulation of the system, WAVE allows the user to rerun the simulation at a different temperature by following these steps (Figure 184):

1. Click on the dropdown arrow under "Temperature" in the Summary Report Tab.
   Select the appropriate temperature value:
   a. Design temperature

   b. Maximum temperature

   c. Minimum temperature

   d. Another values (using the 'Specify') option.

2. Click on the "Refresh Report" button (see Figure 184).

The report will be updated with recalculated values. WAVE will use the existing resin volumes and vessel geometry obtained during the previous simulation and the "Length of Operating Cycles" (or "Specific Velocity") specified on the IX Initialization Window.

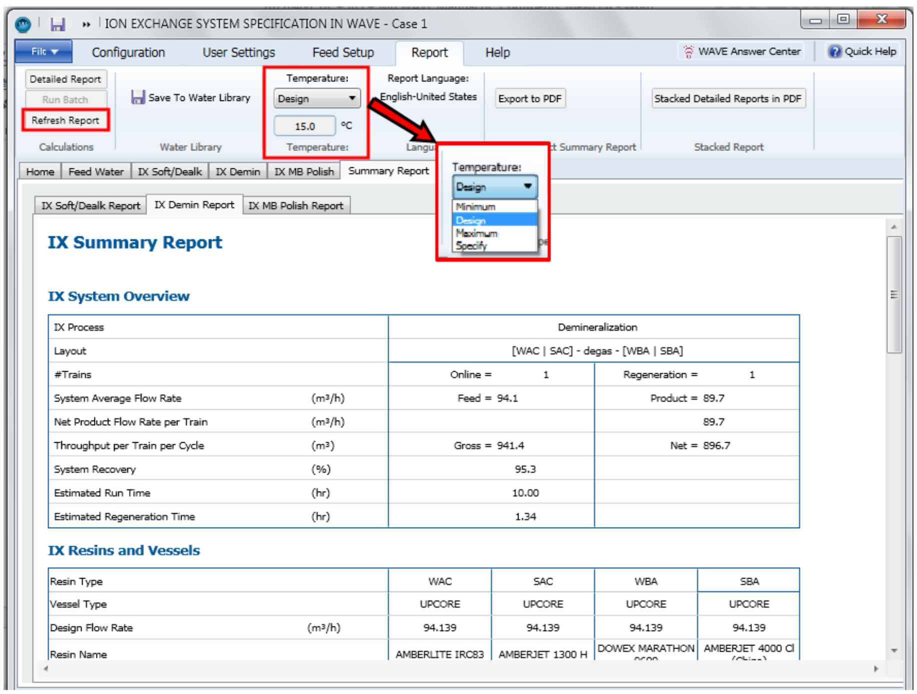


Figure 184. Re-evaluating the design at a different feed temperature

Notes:

- The same Minimum, Maximum and Design Temperatures specified in the Feed Water Tab would be shown in the dropdown list in the Calculate & Report Tab.
- The temperature specified at this step would not be propagated to other windows (e.g. the Chemical Adjustment Popup Window)

5.2.4 Define Recovery

WAVE automatically sends the System Recovery calculated at the Report Tab to the Home Tab. However, if needed the recovery can be modified. This can be done through the following steps:

1. Click on the Home Tab and right-click on the Technology symbol
2. Select “Define Recovery” from the dropdown list. The Define Recovery Popup Window would appear
3. Select the radio button next to selected option and click “OK”:
    - Basic Default: This is the default recovery that WAVE is assuming when starting the design
    - Specify: User specified initial recovery value that WAVE will assume when starting the design.
    - Based on IX Process configuration: this option will only appear once the summary report has been generated. This is the calculated IX Process recovery based on the design inputs and it is the recovery that WAVE will be using.

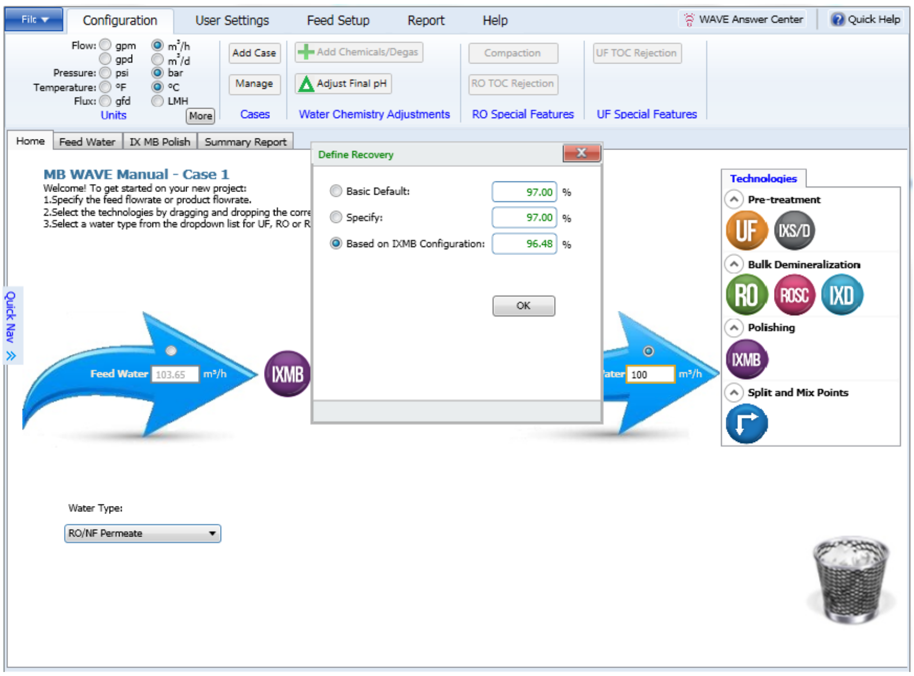


Figure 185. WAVE define recovery option

5.2.5 Handling the Reports (Saving & Exporting)

The Summary Report serves as a quick look at the results. The Summary Report can be exported as a PDF document to a folder location of the user's choice.

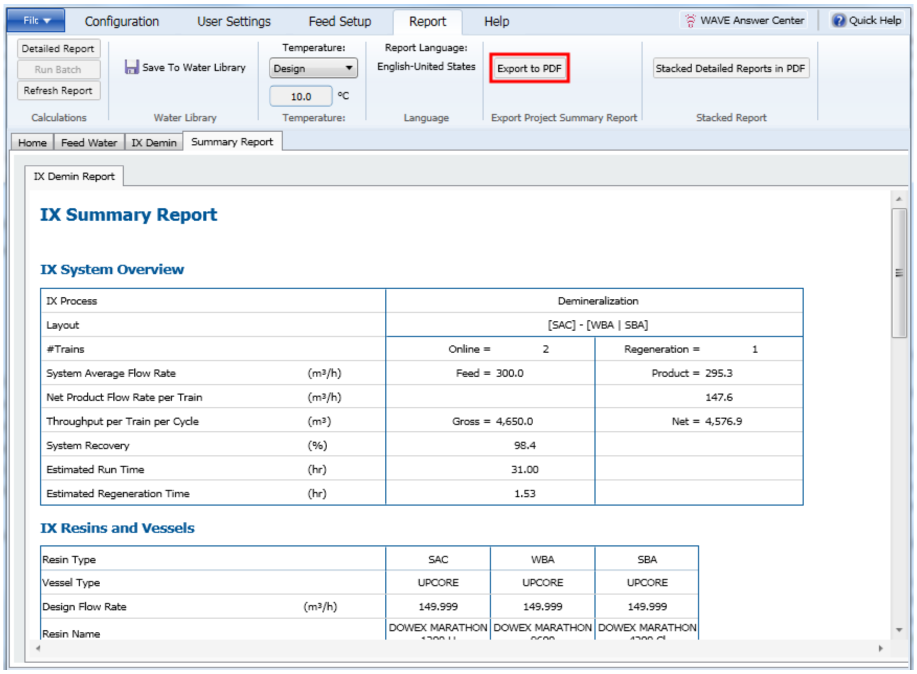


Figure 186. Export of Summary Report in WAVE as PDF

The Detailed reports can be exported to PDF, Excel or Word as shown in Figures below. All of these options lead to a folder location where the user can save the PDF, Excel or Word file.

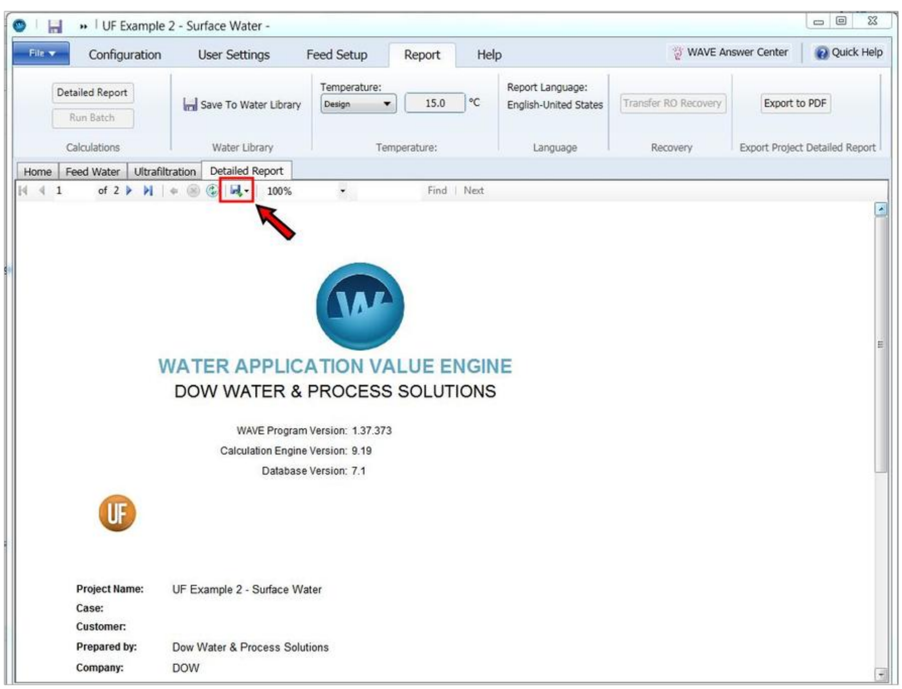


Figure 187. Export of Detailed Reports in WAVE - selecting the dropdown

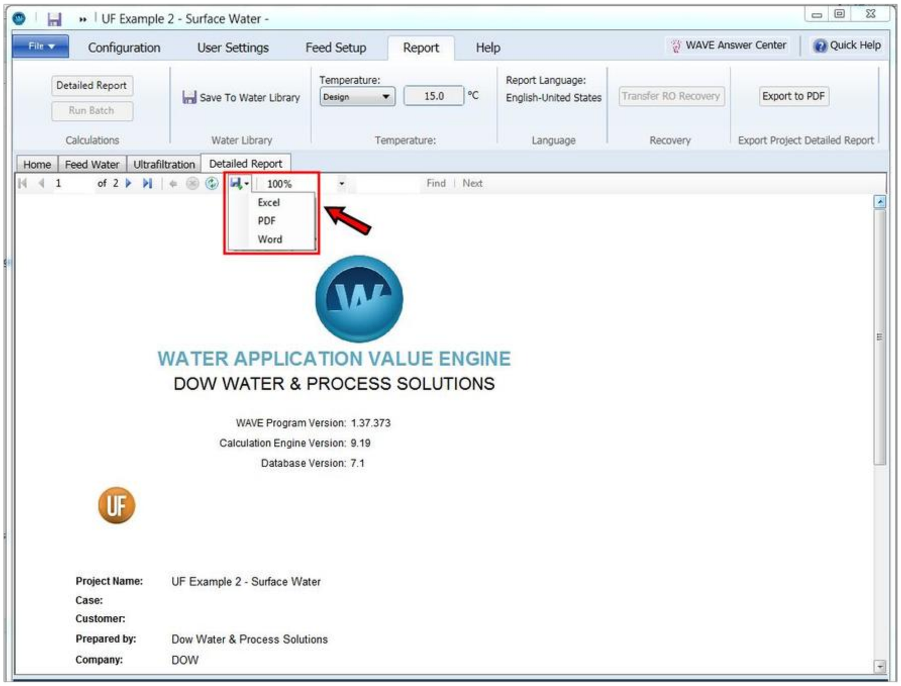


Figure 188. Export of Detailed Reports in WAVE - selecting the option

It is also possible to create stacked report. By clicking this option, WAVE will create detailed report of all the different cases selected in one single pdf file.

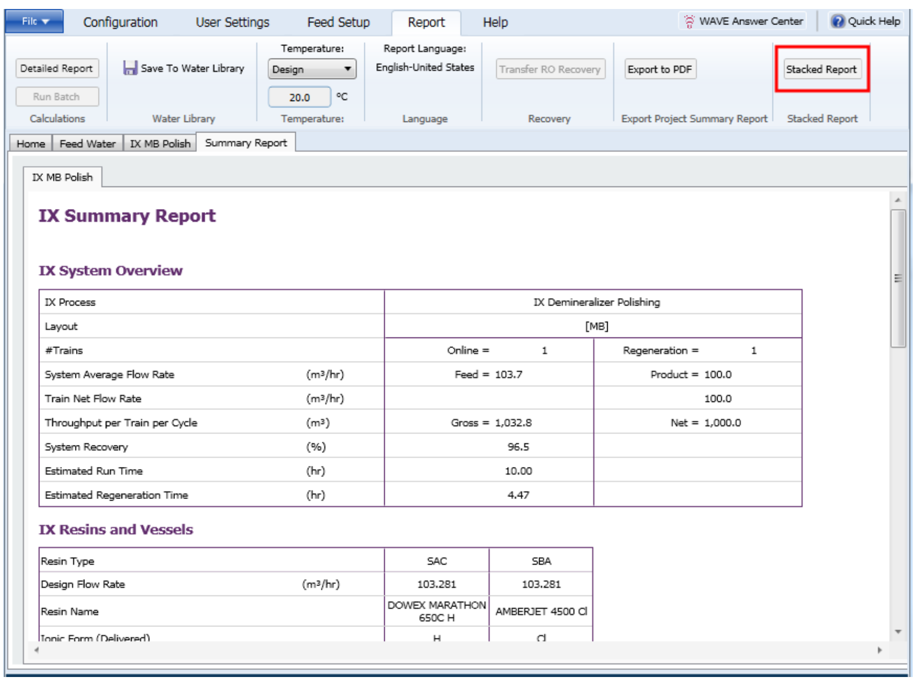


Figure 189. Stacked report in WAVE

6 Case Management

WAVE allows users to create variations of a water treatment process by defining multiple cases. Case management in WAVE involves the following:

6.1 Adding New Cases

New Cases can be created in WAVE using two ways:

6.1.1 Using the Add Case button in the Home Tab

New cases can be defined in WAVE by clicking on the "Add Case" button in the Home tab (Figure 190).

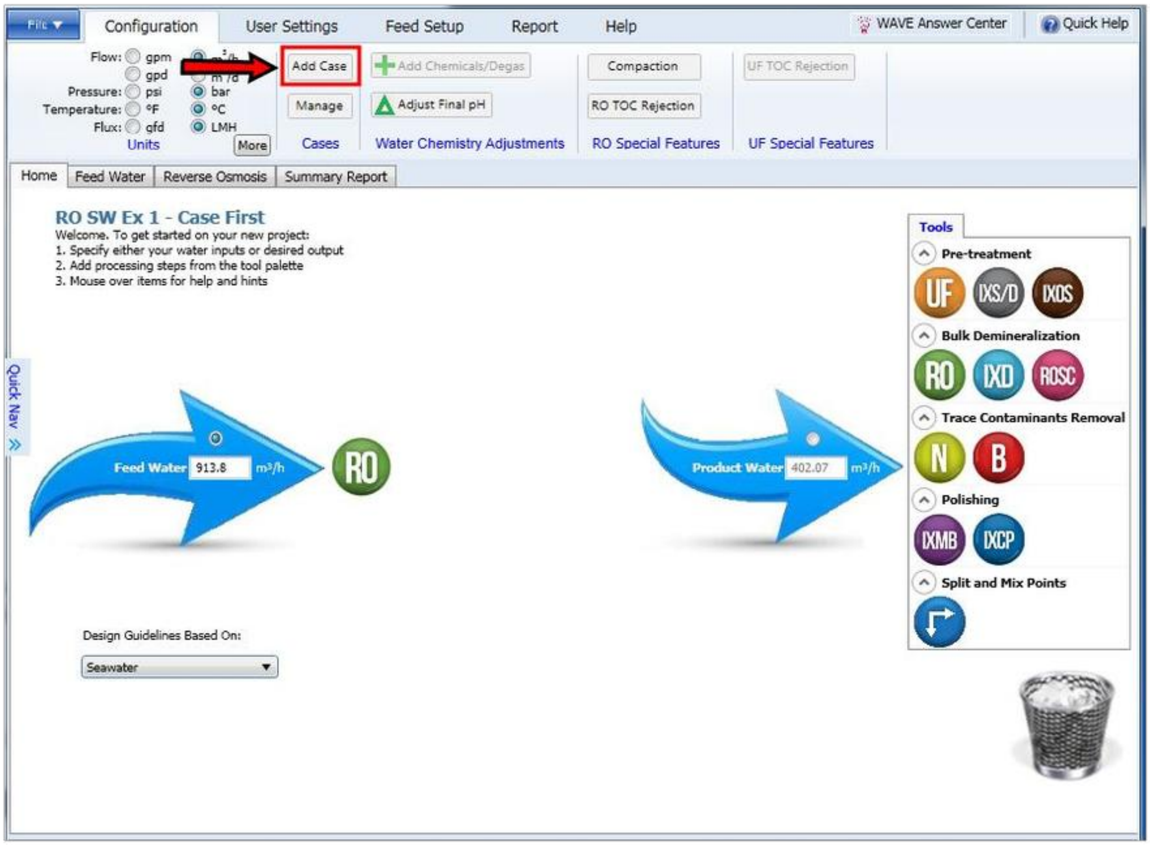


Figure 190. Creating a new case using the Add Case button from the Home window

Notes:

- By default, WAVE creates a case when a new project is started
- By selecting a case of interest (Case A), then right-clicking on it and clicking on the "Add Case" button, the user can create multiple copies of Case A.

6.1.2 Using the Add Case button in the Case Manager Window

New cases can be defined in WAVE as follows:

1. Click on the “Manage” button in the Home Tab (as shown in Figure 191)

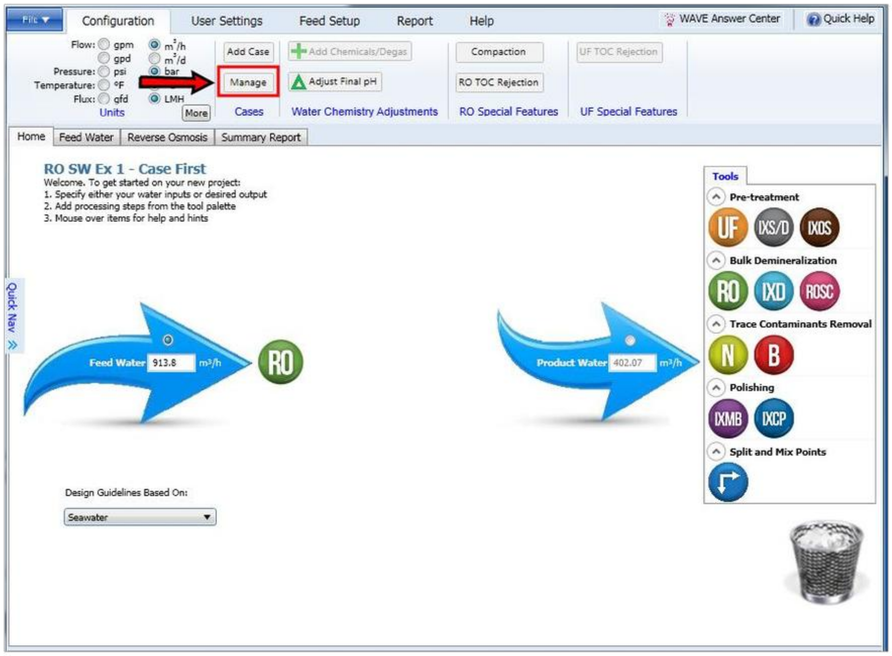


Figure 191. Creating a new case using the Case Manger - accessing the Case Manager

2. Select the case of interest and click on “Add” in the Case Manager window (Figure 192).

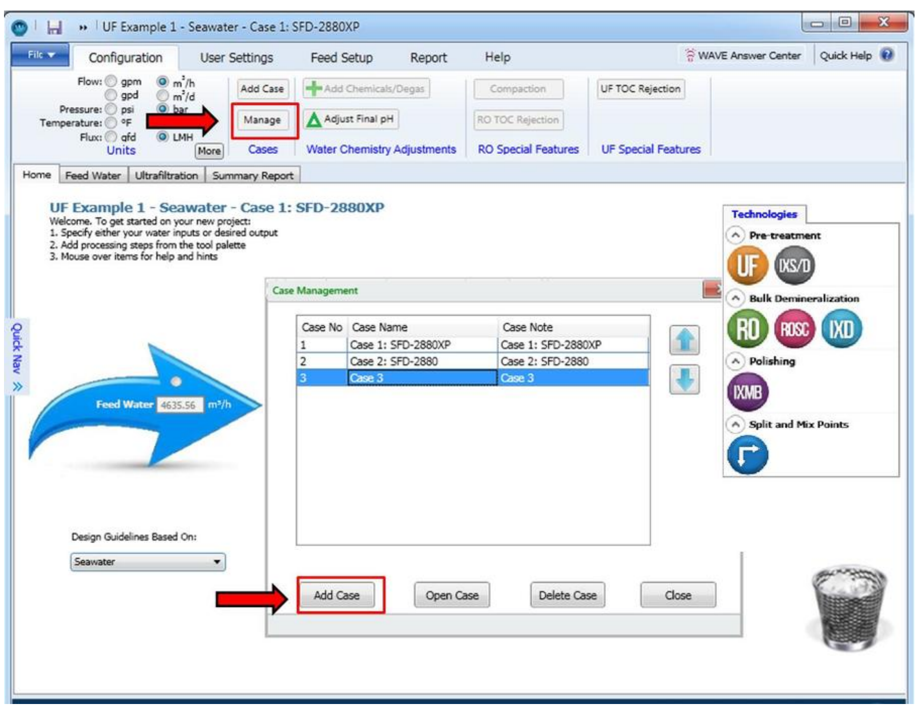


Figure 192. Creating a new case using the Case Manger Add Case button

3. After the case is created, click on "Close" (Figure 193).

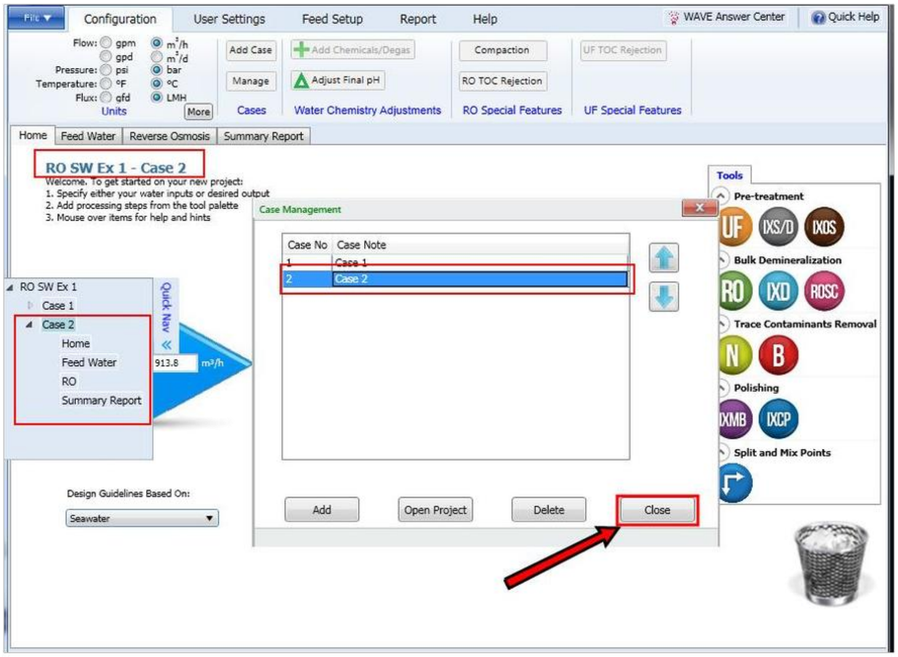


Figure 193. New case creation and where the user is notified

Notes:

- By default, WAVE creates a case when a new project is started
- Users can see that a new case is created by looking at the name of the project displayed at the Case Management window and the Quick Nav window (as shown in Figure 193).

6.2 Accessing Cases

Cases which have been created in WAVE can be accessed in three ways:

6.2.1 Using the Case Management Window

The list of Cases that have been created can be seen from the Case Management window by clicking on the "Manage" button as shown in Figure 194 and Figure 195. The Case Management Window allows the user to order the different cases and rename them.

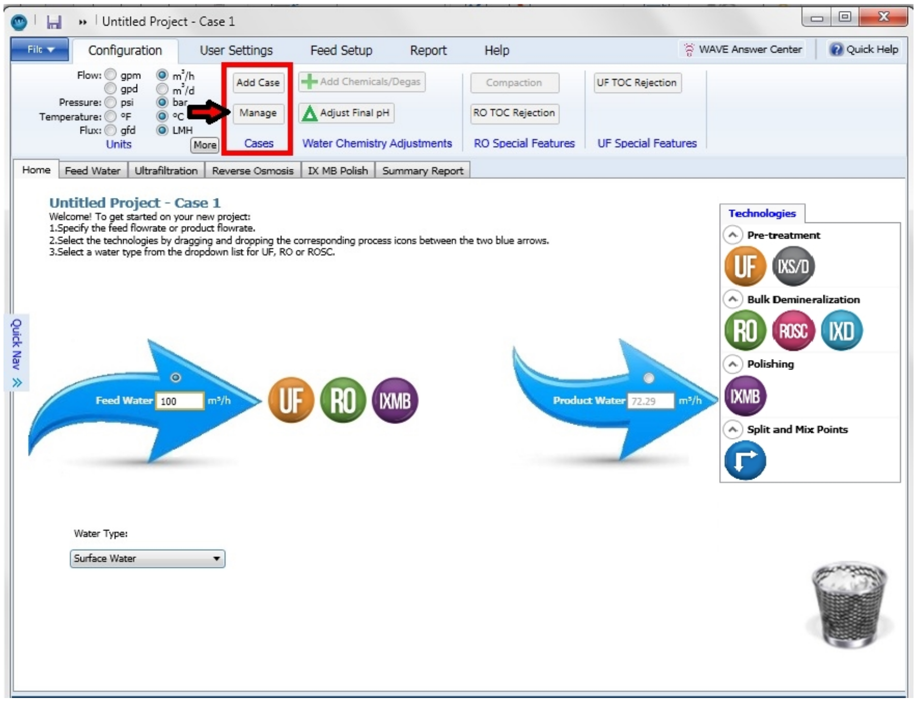


Figure 194. Accessing the Case Management window

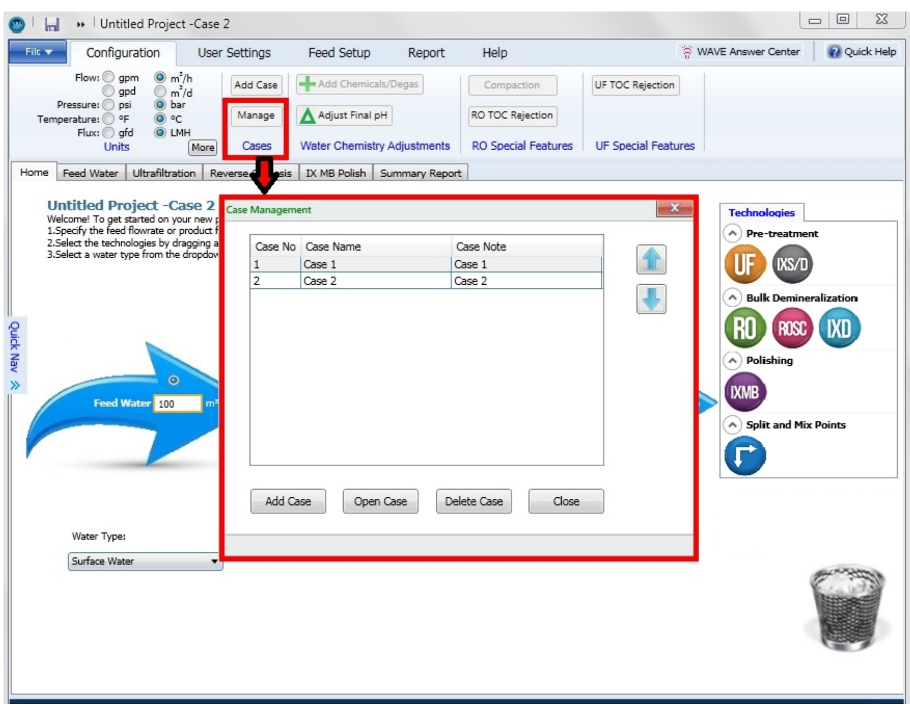


Figure 195. The Case Management window

Note: The Case Management window allows the user to reorder the Cases and rename them. It does not let the user delete, add or open a case.

6.2.2 Using the Quick-Nav Window

The Quick-Nav Window, accessible from every Tab except for the Summary Report Tab, is another way to access the list of cases (Figure 196 and Figure 197). From the Quick - Nav window, the user can open or delete a Case.

- WAVE prevents the user from deleting the last or only case in the Quick-Nav window.
- The Quick-Nav window does not allow the user to add or reorder a case.

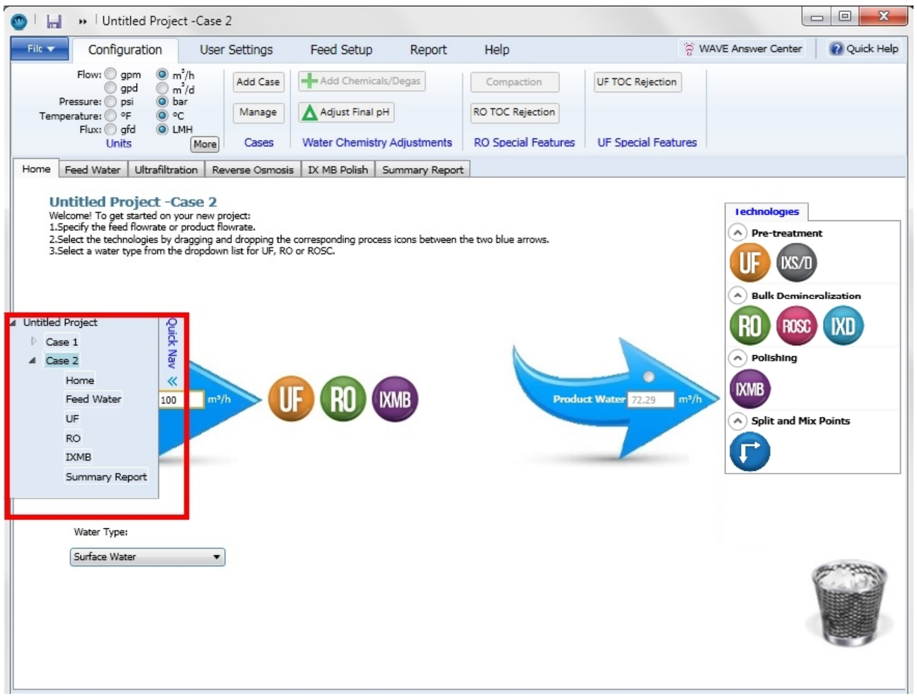


Figure 196. Accessing cases through the Quick-Nav window - accessing Quick Nav

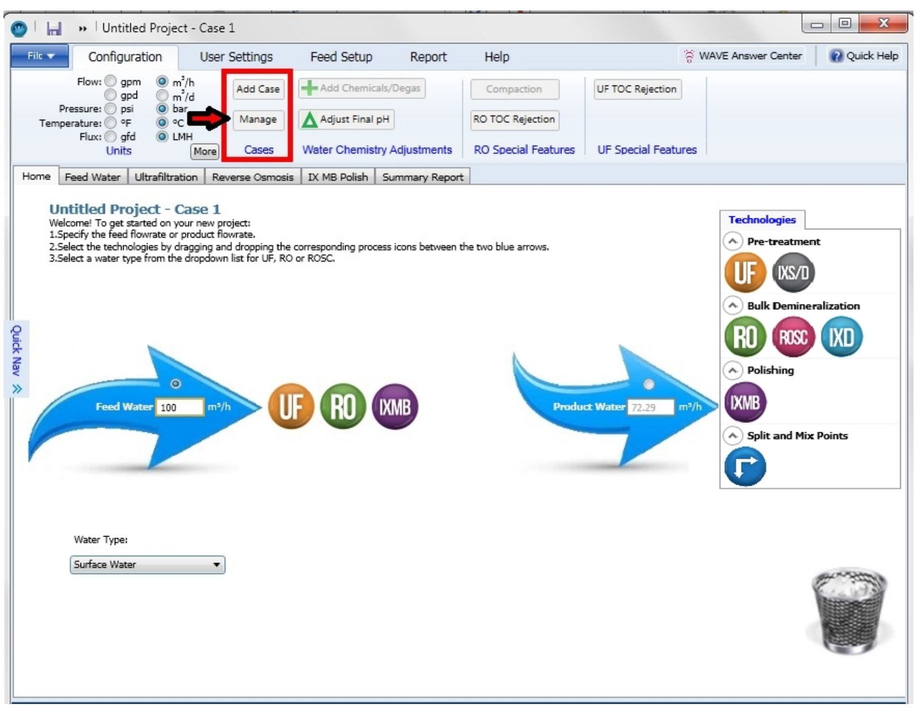


Figure 197. Accessing the Case Management window

6.2.3 Using the Project Open Window

A third way of accessing is by using the “Open Existing Project” window . The steps are:

1. Click on “File”, then select “Open Project” (as shown in Figure 198)
2. Click on the “Show Cases” checkbox, as shown in Figure 199. The cases in that project are displayed as shown in Figure 200.

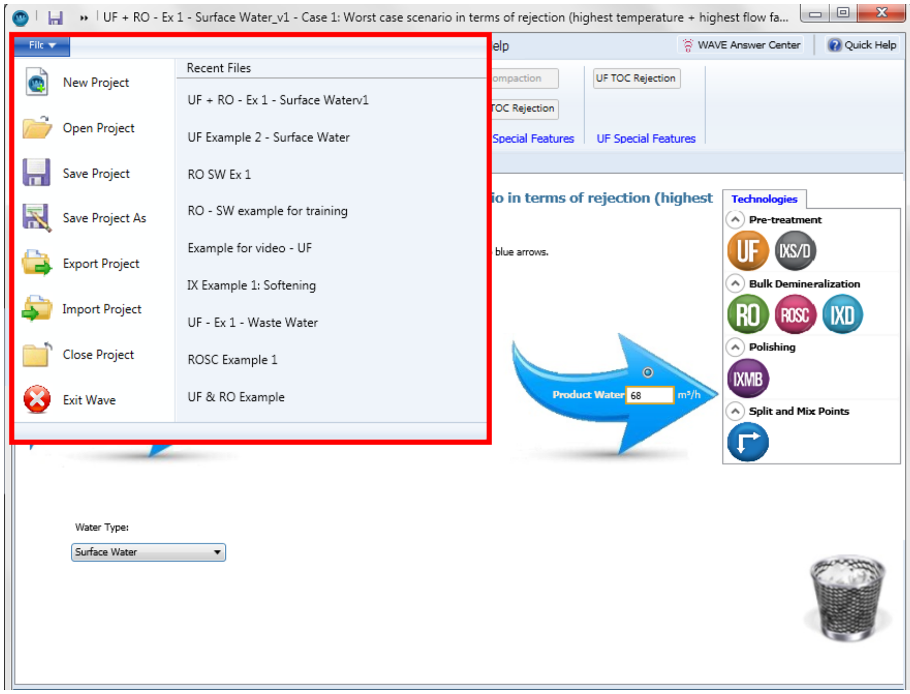


Figure 198. Choosing the ‘Open Project’

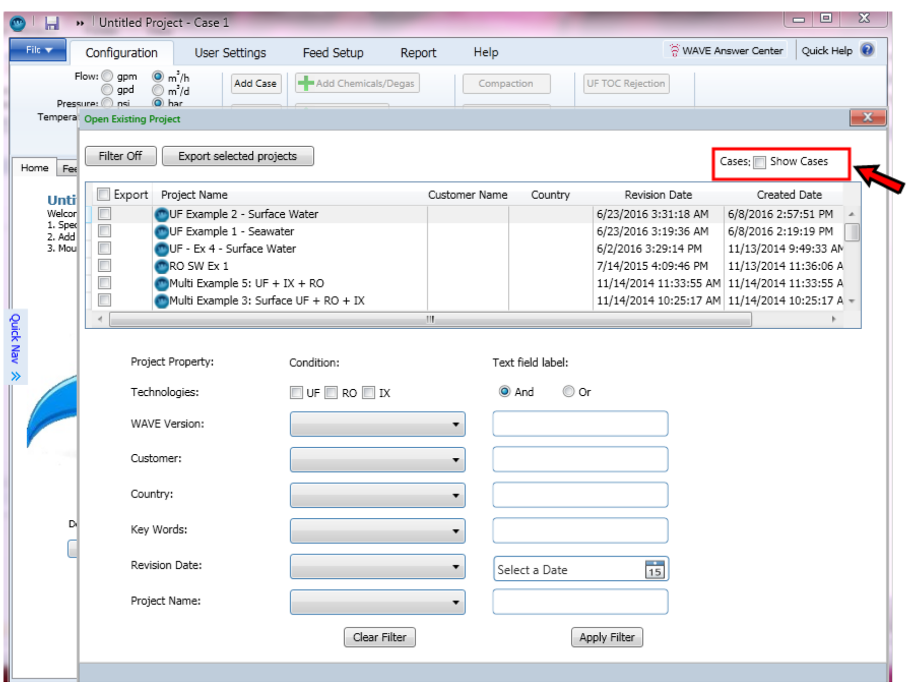


Figure 199. Selecting 'Show Cases'.

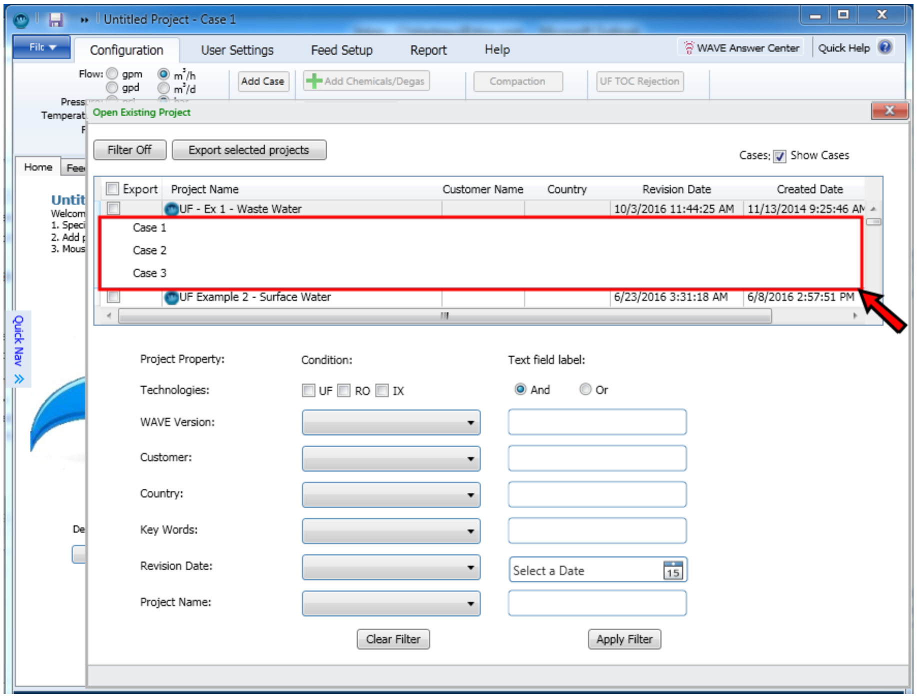


Figure 200. Display of cases in the 'Open Existing Projects' window.

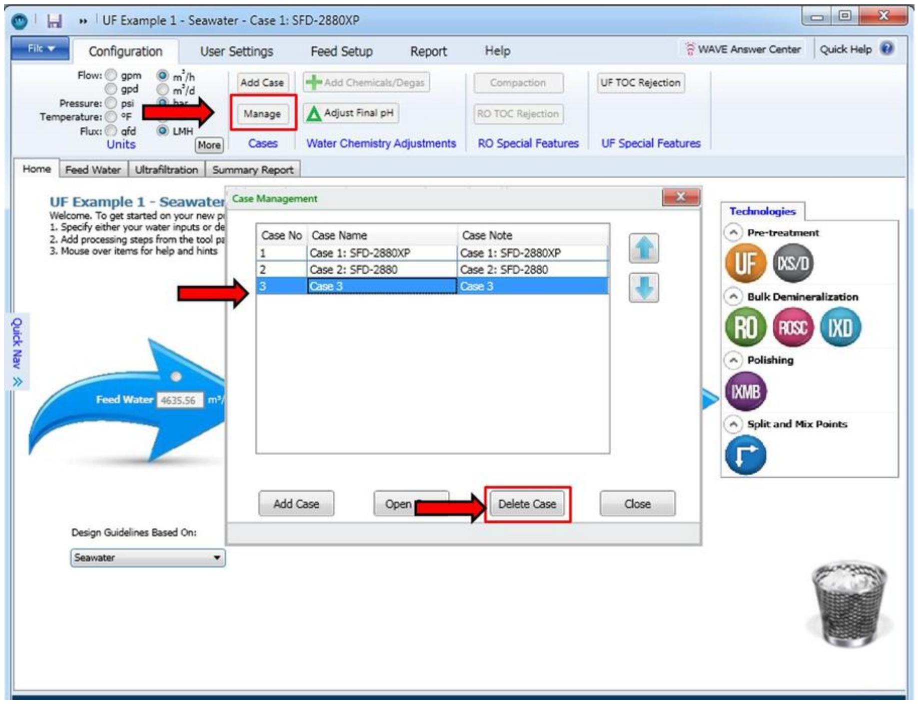
Notes:

- By right-clicking on the Case of interest, the user can Open, Delete and Rename a Case in the “Open Existing Project” window. The user can promote one of the cases to a ‘root project’ so that more cases can be generated from it.
- The ‘Open Existing Project’ window does not allow the user to re-order the cases or create a new case.

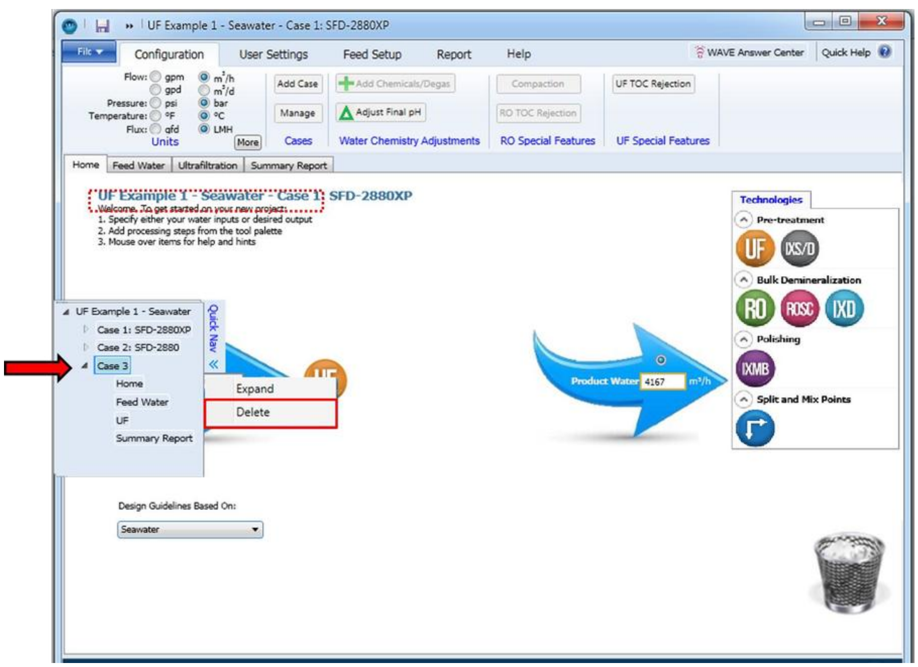
6.3 Deleting Cases

Cases can be deleted in WAVE in one of three ways:

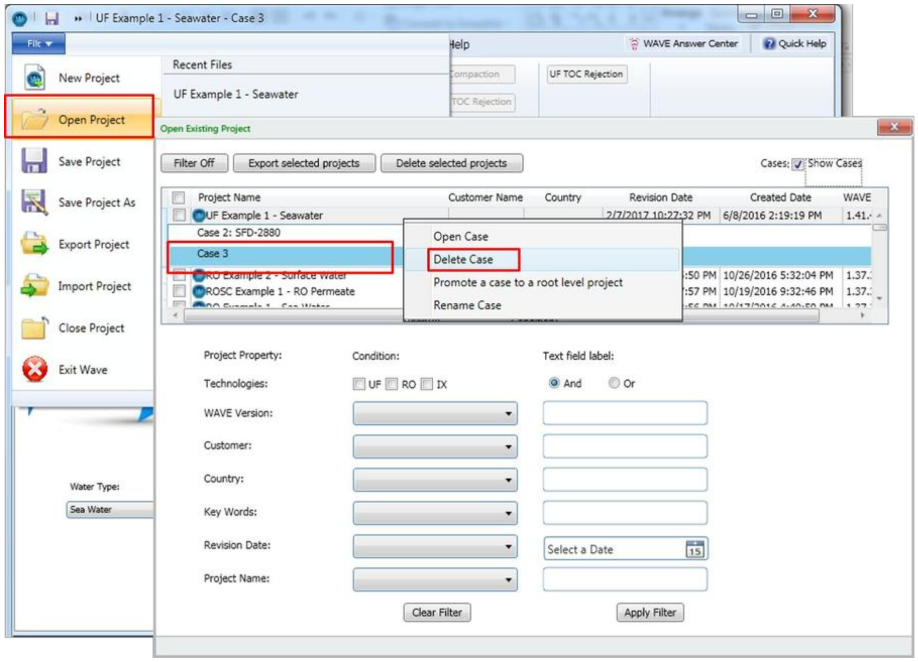
1. Using the Case Manager: Cases can be deleted by selecting them and clicking on 'Delete Project'.



2. Using the Quick-Nav Window: Cases can be deleted by right clicking on them and selecting "Delete".



3. Using the Open Existing Project Window: Cases can be deleted by right clicking on them and selecting "Delete Case".



6.4 Saving and Exporting

6.4.1 Saving

WAVE projects can be saved using "File" then "Save" or "Save as" as shown. . The user is prompted to provide a name for the project the first time it is saved.

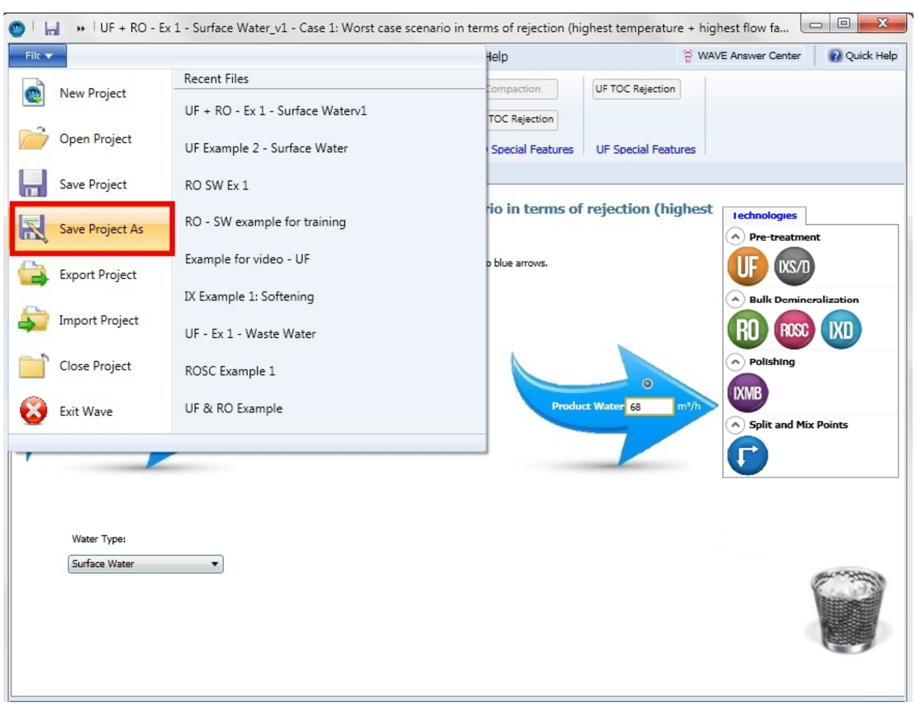


Figure 201. Project saving in WAVE

6.4.2 Exporting

WAVE projects are saved in a database and cannot be shared. However they can be exported as DWPX files which can be saved and e-mailed. If the user clicks on “Export” they would be directed to a folder to which they can export the Project. By the same token, a user can Import a project from a folder using the Import button.

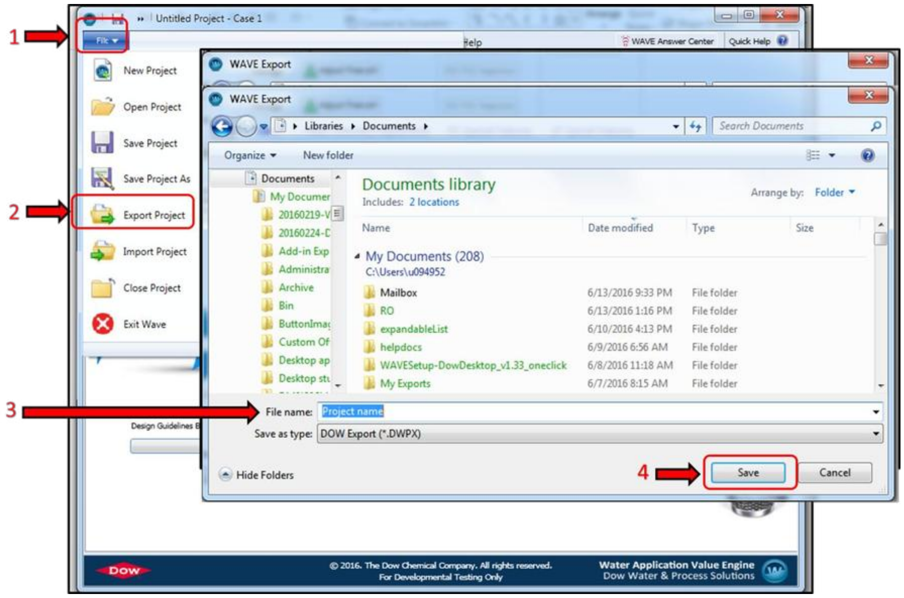


Figure 202. Project export in WAVE

Notes:

- WAVE does not allow a user to export a project that has not been saved
- Importing a DWPX file will bring the project into the “Open Existing Project” window. The user has to go to the “Open Existing Project” window from File to open the Project.

6 Definitions of Terms and Abbreviations

Absolute density	Weight of wet resin that displaces a unit volume, expressed as grams per unit volume in a specific ionic form.
Air mixing	Process of using air to mix two ion exchange materials of different densities in a water
Air Scour	Cleaning method where air is used to shake the fibers and help to dislodge the solids from its surface. Also known as Air Scrub.
Alk leak at end-point	The normal end-point for a WAC resin is 10% alkalinity leakage. In this condition, the downstream SAC resin should remove the permanent hardness and the monovalent cations. This situation generally leads to a big discrepancy between WAC (large) and SAC (low) resin volumes. Increasing the end point value above 10% means that the SAC resin has to deal with a part of alkalinity, resulting in a better: utilization of both resins and better optimization. This item can be entered as any value between 10 and 80%.
Amount NaOH used	The amount of NaOH used for one regeneration expressed as equivalent unit.
Anion salinity	The gross ionic load on the anion exchange resins between two regenerations.
Anion exchange resin	A positively charged synthetic particle that can freely exchange associated anions based on differences in the selectivities of the anions. Also referred to as anion resin.
Attrition	Breakage and abrasion of resin beads occurring when the beads rub against other beads or other solids.
Backwash	Hydraulic cleaning method where filtrate water is pumped from the filtrate to the feed side of the membrane in order to remove accumulated foulants. Also known as Backflush or Backpulse. Upward flow of water through an ion exchange resin bed to remove foreign material and reclassify the bed after exhaustion and prior to regeneration. Also used to reduce compaction of the bed.
Base exchange	Exchange of cations between a solution and cation exchange resin.
Batch operation:	Method of using ion exchange resins in which the resin and the solution to be treated are mixed in a vessel, and the liquid is decanted or filtered off after equilibrium is attained.
Bed	Ion exchange resin contained in a column.
Bed depth	Depth of ion exchange resin in a column.
Bed expansion	Separation and rise of ion exchange resin beads in a column during backwashing.
Bed volume	Volume of ion exchange material of specified ionic form contained in a column or
Bed volume per hour	Measure of the volume flow rate through an ion exchange material contained in a column or operating unit, expressed as BV/h, $m^3/h/m^3$, or $gal/min/ft^3$.
Bed warm-up	Step just prior to regenerant injection where hot dilution water is added to the resin bed to heat the bed to the appropriate temperature. This is to enhance polymerized silica removal.
Boiler feed water	Water used in steam boilers and some industrial processes. Boiler feed water may possibly be raw water, treated water, condensate, or mixtures, depending on the need.
Breakthrough	Volume of effluent where the concentration of the exchanging ion in the effluent reaches a predetermined limit. This point is usually the limit of the exhaustion cycle and where the backwash cycle begins.
Capacity	Number of equivalents of exchangeable ion per unit volume, unit wet weight, or dry weight of an ion exchange material in specified ionic form.
Cation exchange resin	Negatively charged synthetic particle that can freely exchange associated cations based on differences in the selectivities of the cations. Also referred to as cation resin.
Channeling	Creation of isolated paths of lower resistance in an ion exchange resin bed caused by the introduction of air pockets, dirt, or other factors that result in uneven pressure gradients in the bed. Channeling prevents the liquid being processed from uniformly contacting the entire resin bed.

Chemically Enhanced Backwash (CEB)	Chemical cleaning method, typically initiated automatically, where some chemicals are added into the Backwash stream in order to help improve the effectiveness of the cleaning. Usually includes a soaking step.
Chemical stability	Ability of an ion exchange resin to resist changes in its physical properties when in contact with aggressive chemical solutions such as oxidizing agents. Also the ability of an ion exchange resin to resist inherent degradation due to the chemical structure of the resin.
Chloride anion dealkalization	Anion exchange system that is regenerated with salt and caustic and exchanges chloride ions for bicarbonate and sulfate ions in the water being treated.
Classification	Obtained by backwashing an ion exchange resin bed, which results in a bed that is graduated in resin bead size from coarse on the bottom to fine on the top. This is less important when using uniform particle size resins
Clean-In-Place (CIP)	Chemical cleaning method, typically initiated manually, where one or several chemical solutions are consecutively applied in the ultrafiltration trains in order to restore clean membrane condition.
Clumping	Formation of agglomerates in an ion exchange bed due to fouling or electrostatic charges.
Co-current operation	Ion exchange operation in which the process water and regenerant are passed through the bed in the same direction, normally downflow.
Color throw	Color imparted to a liquid from an ion exchange resin.
Column operation	Most common method for employing ion exchange in which the liquid to be treated passes through a fixed bed of ion exchange resin.
Concentrate	The water stream leaving the membrane system as waste.
Condensate polisher	Use of a cation resin or mixed-bed column to remove impurities from condensate.
Conductivity	Ability of a current to flow through water as a measure of its ionic concentration, measured in micromhos/cm (μmho/cm) or microsiemens/cm (μS/cm).
Contact time	Amount of time that the process liquid spends in the ion exchange bed, expressed in minutes. Determined by dividing the bed volume by the flow rate, using consistent units.
Counter-current operation	Ion exchange operation in which the process liquid and regenerant flows are in opposite directions. Also referred to as counter-flow operation.
Deaerator	Device that reduces oxygen as well as CO_2 and all other gases to a very low level. It is a preferred as a means of CO_2 reduction when demineralizing boiler water make-up. It eliminates water pollution and reduces corrosion problems when transferring water through steel equipment. Usually results in longer anion exchange resin life.
Dealkalization	Anion exchange process for the removal or reduction of alkalinity in a water supply.
Decationization	Exchange of cations for hydrogen ions by a strong acid cation exchange material in the hydrogen form. See Salt splitting.
Degasifier	Used to reduce carbon dioxide content of the effluent from hydrogen cation exchangers. Reduces CO_2 to approximately 5–10 ppm but saturates water with air. Also referred to as a decarbonator.
Degradation	Physical or chemical reduction of ion exchange properties due to type of service, solution, concentration used, heat, or aggressive operating conditions. Some effects are capacity loss, particle size reduction, excessive swelling, or combinations of the above.
Deionization	Removal of ionizable (soluble) constituents and silica from a solution by ion exchange processing. Normally performed by passing the solution through the hydrogen form of cation exchange resin and through the hydroxide form of an anion exchange resin, either as a two-step operation or as an operation in which a single bed containing a mixture of the two resins is employed.
Deionized water	Water that has had all dissolved ionic constituents removed. Cation and anion exchange resins, when properly used together, will deionize water.
Dissociation	Process of ionization of an electrolyte or salt upon being dissolved in water, forming cations and anions.

Distributor	Piping inside an ion exchange vessel that evenly distributes flow across the resin bed.
Double pass	Process by which a stream is treated twice in series by ion exchange resins. Normally a cation exchange resin and anion exchange resin are followed by a mixed bed or another cation exchange resin and anion exchange resin step
Downflow	Operation of an ion exchange column in which the regenerant enters the top of the ion exchange column and is withdrawn from the bottom. This is the conventional direction of water flow in a co-current ion exchange column.
Dry weight capacity	Amount of exchange capacity present in a unit weight of dried resin.
Eductor	Device that draws a solution into the water stream by using a flow of water to create a vacuum.
Effective size	Particle size expressed in millimeters equal to the 90% retention size determined from a particle size analysis.
Efficiency	Measure of the quantity of regenerant required to remove a chemical equivalent weight of contaminant in the influent water. For a sodium softener, this is usually expressed as pounds of salt per kilogram or kg salt per equivalent of hardness removed.
Effluent	The solution that emerges from an ion exchange column or vessel.
Eluate	The solution resulting from an elution process.
Elution	The stripping of sorbed ions from an ion exchange resin by passing solutions containing other ions in relatively high concentrations through the resin column.
Eductor	Device that draws a solution into the water stream by using a flow of water to create a vacuum.
Effective size	Particle size expressed in millimeters equal to the 90% retention size determined from a particle size analysis.
Exchange sites	The reactive groups on an ion exchange resin.
Exchanger bed	Ion exchange resin contained in a suitable vessel and supported by material, such as grated gravel, screen-wrapped pipe, or perforated plate, which also acts as a liquid distribution system.
Exhaustion	Step in an ion exchange cycle in which the undesirable ions are removed from the liquid being processed. When the supply of ions on the ion exchange resin that are being exchanged for the ions in the liquid being processed is almost depleted, the resin is said to be exhausted.
Fast rinse	Portion of the rinse that follows the slow rinse. Usually passed through the ion exchange bed at the service flow rate.
Feed	The water stream entering the membrane system.
Flow Factor	Factor of permeability applied to model boundary conditions in a RO/ROSC/NF designs.
Filtrate	The water stream that goes through the membrane, and is free from impurities.
Flow	Feed flow is the rate of feedwater introduced to the membrane element or membrane system, usually measured in gallons per minute (GPM) or cubic meters per hour (m3/h).
Flux	The throughput of a membrane filtration system expressed as flow per unit of membrane area (e.g., gallons per square foot per day (GFD) or liters per hour per square meter (LMH).
FMA leak at end-point	The normal end-point for a WBA resin corresponds to the chloride breakthrough that can be set just above 0%. In this condition, the downstream SBA resin should remove the carbon dioxide and silica ions. This situation generally leads to a big discrepancy between WBA (large) and SBA (low) volumes. Increasing the value above 0% means that the SBA has to deal with a part of FMA (mainly chloride), resulting in a better utilization of both resins and a better optimization. This item can be entered as any value between 0 and 80%.
Forward Flush	Step in a UF backwash sequence during which, feed water is used to rinse the system to remove remaining solids and the air that might have got trapped in the system during the precedent steps. Water flows on the outside of the fibers (feed side) with the filtrate valve closed, and exits through the module top outlet.
Free mineral acidity	Due to the presence of acids such as H_2SO_4, HCl, and nitric acid (HNO_3), expressed in ppm or mg/L as calcium carbonate.

Freeboard	Space provided above the resin bed in the column to accommodate the expansion of resin particles during backwashing.
Functional group	Atom or group of atoms on an ion exchange resin that gives the resin its specific chemical characteristics.
Gel	Term applied to the bead structure of certain ion exchange resins that have a microporous matrix structure with small pores generally <10 Å. Gel resins offer good operating capacity and regeneration efficiency. Porous gel resins also exhibit good resistance to organic fouling.
Gross throughput	The volume of water that the resin is able to deionize. It includes the water used for regeneration, in contrast to the NET throughput that excludes it.
Hardness, total	Currently defined as the sum of calcium and magnesium concentrations, both expressed as calcium carbonate in ppm or mg/L.
Hydraulic classification	Tendency of small resin particles to rise to the top of the resin bed during a backwash operation and the tendency of large resin particles to settle to the bottom.
Hydrogen cation exchanger	Term used to describe a cation resin regenerated with acid to exchange hydrogen ions (H+) for other cations.
Hydrogen cycle	Cation exchange resin operation in which the regenerated ionic form of the resin is the hydrogen form.
Hydroxide cycle	Anion exchange operation in which the regenerated form of the ion exchange material is the hydroxide form.
Influent	Solution entering an ion exchange column.
Integrity Test	Physical test applied to a membrane unit to detect integrity breaches.
Internally Staged Design	The principle of Internally Staged Design (ISD) is that elements with the lowest production and highest rejection are installed in the first positions and elements with the highest production in the rear positions of the vessel.
Interstitial volume	Space between the particles in an ion exchange resin bed.
Ion exchange	Process by which ionic impurities in water are attached to active groups on and in an ion exchange resin, and more desirable ions are discharged into water.
Ionic form	The resin performances are always reported to the shrunken form of the resins. It corresponds to the following ionic forms: • Hydrogen for WAC • Sodium for SAC • Free base for WBA • Chloride for SBA
Ionic strength	Half of the sum of the product of ion concentrations and the square of their charges.
Ionization	Separation of part or all of the solute molecules into positive (cationic) and negative (anionic) ions in a dissociating medium such as water.
Inert resin volume	The value displayed corresponds to the volume of inert material in each vessel or in each compartment. For plant retrofit or design using standard vessels, if there is no top nozzle plate, the value includes the volume of material required to fill the dome, providing you checked the corresponding box in plant retrofit step.
ISD	Internally Staged Design
Layered bed	Two ion exchange materials (e.g., weak and strong base anion resins) with sufficient differences in density and hydraulic characteristics to be layered in the same vessel, in place of two separate vessels.

Langelier Saturation Index (LSI)	WAVE uses ASTM International practice D 3739 (Standard Practice for Calculation and Adjustment of the Langelier Saturation Index for Reverse Osmosis) as the basis for the LSI calculations performed. The LSI is an indicator used to determine the need for calcium carbonate scale control. It is applicable for water streams containing up to 10,000 mg/L of total dissolved solids. For water streams containing greater than 10,000 mg/L of total dissolved solids, the Stiff & Davis Stability Index is preferred.
Leakage (hardness, sodium, silica, etc.)	Phenomenon caused by incomplete regeneration of an ion exchange bed. Since complete regeneration is usually inefficient, most ion exchange processes operate at one-half to one-third of the total capacity of the ion exchange system.
Macroporous	Term applied to the bead structure of certain ion exchange resins that have a tough, rigid structure with large discrete pores. Macroporous resins offer good resistance to physical, thermal, and osmotic shock and chemical oxidation. Macroporous anion resins also exhibit good resistance to organic fouling.
Mixed bed	Use of a mixture of cation and anion resins in the same column to produce water of extremely high quality.
Module	This refers to the simplest unit composed of the membranes, the vessel, the end-caps, the feed and air inlets, the filtrate outlet and the waste outlet. Several modules form a membrane train, rack, bank or skid.
Molality	Number of gram-molecules weight of a solute per kilogram of solvent.
Molarity	Number of gram-molecules weight of a solute per liter of solution.
NF	Nanofiltration
Operating capacity	Portion of the total exchange capacity of an ion exchange resin bed that is used in a practical ion exchange operation. Commonly expressed in kilograms per cubic foot (kg/ft^3) or milliequivalents per liter (meq/L).
Operating cycle	Complete ion exchange process consisting of a backwash, regeneration, rinse, and service run.
Osmotic shock	Expansion or contraction of resin beads due to volume changes imposed by repeated applications of dilute and concentrated solutions.
Osmotic stability	Ability of an ion exchange material to resist physical degradation due to osmotic shock.
Passage	The percentage of dissolved constituents (contaminants) in the feedwater allowed to pass through the membrane.
Permeate	The purified product water produced by a membrane system.
Permeate Split	Capability of splitting a portion of the pass 1 permeate from the first stage to the final system permeate.
pH	It is a numeric scale used to express the acidity or alkalinity of the water. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. Pure water has a pH of 7 and is neutral. In water, high pH causes a bitter taste, water pipes and equipment become encrusted with deposits. Low-pH water will corrode or dissolve metals and other substances.
Polisher	Mixed-bed ion exchange unit usually installed after a two-bed deionizer system to remove the last traces of undesirable ions.
Polydispersed resin	Resin composed of particles of a wide range of particle sizes.
Pressure drop	Loss in liquid pressure resulting from the passage of the solution through the bed of ion exchange resin.
Pretreatment	A series of steps that includes flocculation, settling, filtration, or any treatment water receives prior to ion exchange

Process water	Any water mixed with a product, or becoming part of a product, or used to wash a product. These supplies require various kinds of treatment such as clarification and filtration. In many cases ion exchange resins are used to soften, dealkalize, or completely deionize the water.
Recovery	The ratio of feed water that is converted to filtrate. Recovery equals to filtrate flow produced by the membrane unit divided by the feed flow and is expressed as percentage
Regenerant	Chemical used to convert an ion exchange resin to the desired ionic form for reuse.
Regeneration	Displacement from the ion exchange resin of the ions removed from the process solution. This may be performed either by co-current or counter-current operation. Lower ion leakages are typically obtained with counter-current regeneration at comparable regenerant dosages.
Regeneration efficiency	Measure of the amount of capacity of an ion exchange resin compared to the amount of regenerant applied. This is expressed as a ratio of equivalents of capacity to equivalents of regenerant and is therefore <100%.
Regeneration level	Amount of regenerant used per cycle. Commonly expressed in lb/ft^3 of resin or g/L of resin. Also referred to as regeneration dosage.
Rejection	The percentage of solute concentration removed from system feedwater by the membrane. In reverse osmosis, a high rejection of total dissolved solids (TDS) is important, while in nanofiltration the solutes of interest are specific, e.g. low rejection for hardness and high rejection for organic matter.
Reversible	Ability of an ion exchange resin to use variations in component concentrations and selectivity to allow a resin to be regenerated.
Rinse	Passage of water through an ion exchange resin bed to flush out excess regenerant.
RO	Reverse Osmosis
ROSC	Reverse Osmosis Small Commercial
RTMP	Transmembrane Pressure (bar or psi). It is the pressure difference between the feed and the filtrate side of the UF module or skid.
Run time	Time between regenerations or the duration of the service cycle.
SAC	Strong Acid Cation
Salt splitting	Conversion of salts to their corresponding acids or bases by passage through strong acid cation or strong base anion exchange resins, respectively.
SBA	Strong Base Anion
Scavenger	Polymer matrix or ion exchange material used to specifically remove organic species from the process liquid before the solution is deionized.
Selectivity	Difference in attraction of one ion over another to an ion exchange resin.
Silt density index(SDI)	Particulate or colloidal fouling can seriously impair performance by lowering UF productivity. An early sign of colloidal fouling is often an increased pressure differential across the system. The particulates or colloids can be bacteria, clay, colloidal silica, and iron corrosion products. The best measure of the colloidal fouling potential of the feedwater is the measurement of Silt Density Index (SDI). The Standard Test Method has been described in ASTM test D 4189-82.
Slow rinse	Portion of the rinse that follows the regenerant solution and is passed through the ion exchange material at the same flow rate as the regenerant.
Sluicing	Method of transporting resin from one tank to another with water. Sluicing is usually used in mixed-bed deionization systems with external regeneration systems.
Sodium form cation resin	Cation exchange resin, regenerated with salt (NaCl). Exchanges sodium ions (Na^+) for metal cations (Mg^{+2}, Ca^{+2}, etc.), forming sodium salts (sulfates, carbonates, etc.).
Stiff & Davis Stability Index (S&DSI)	WAVE uses ASTM International practice D 4582 (Standard Practice for Calculation and Adjustment of the Stiff and Davis Stability Index for Reverse Osmosis) as the basis for the S&DSI calculations performed. The S&DSI is an indicator used to determine the need for calcium carbonate scale control. It is applicable for water streams containing greater than 10,000 mg/L of total dissolved solids. For water streams containing less than 10,000 mg/L of total dissolved solids, use Langelier Saturation Index.
Stability:	Capability of a resin to resist chemical and physical degradation.

Strong acid capacity:	Part of the total cation exchange capacity that is capable of converting neutral salts to their corresponding acids.
Strong acid cation resin:	Resins employed in softening and deionization systems. When regenerated with salt, the sodium ions on the resin will effectively exchange for divalent cations such as calcium and magnesium. When regenerated with H_2SO_4 or HCl, the resin will split neutral salts, converting the salt to its corresponding acid. The resin usually receives its exchange capacity from sulfonic groups.
Strong base anion resin	Resins employed in chloride anion dealkalizers and deionization systems. When regenerated with salt, the chloride ions exchange for bicarbonate and sulfate anions. When regenerated with caustic soda, the resin removes both strong and weak acids from cation exchange resin effluent. The resin usually receives its exchange capacity from quaternary ammonium groups.
Strong base capacity	Part of the total anion exchange capacity capable of converting neutral salts to their corresponding bases.
Throughput	Amount of product water generated during the service cycle.
TOC (Total Organic Carbon)	It is the most widely used parameter to determine the organic content in water. It includes Natural Organic Matter (NOM) and synthetic sources. It is indicative of the tendency of the water to cause organic fouling and biofouling in membranes. It is expressed in mg/L.
TSS (Total Suspended Solids)	It is the measure of the total weight of solids contained in a water sample, and is expressed in mg/L. This parameter is more accurate than turbidity (i.e., turbidity usually does not detect very fine particles).
Total capacity	Maximum exchange ability of an ion exchange resin expressed on a dry weight, wet weight, or wet volume basis.
Train	Single ion exchange system capable of producing the treated water desired, such as a strong acid cation resin bed followed by a strong base anion resin bed, with multiple trains being duplicates of the single system.
Turbidity	Sediments, clay, silt, small particles, solids etc. cause a liquid to appear turbid, "hazy". These particles can, besides, host or shield microorganisms like bacteria and viruses. Turbidity is measured by the intensity of light that passes through the water sample, and expressed in NTU (Nephelometric Turbidity Units). Ultrafiltration gives consistent product water with turbidity values < 0.1 NTU.
Ultrafiltration	A pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.01 – 0.05 µm.
UF	Ultrafiltration
Under drain	Piping inside an ion exchange vessel that evenly collects the treated water after it has passed through the resin bed.
UPCORE™	A version of the Packed bed, counter-current regeneration technology in which process flow is downflow and regeneration is upflow after a compaction step. A floating layer of inert particles is used to provide self-cleaning capability. UPCORE™ (up¢ kō rā) systems are self-cleaning, eliminating the need for backwash and increasing regeneration efficiency and productivity while minimizing leakage. The names comes from UPflow Counter-current Regeneration.
Upflow	Operation of an ion exchange column in which the regenerant enters the bottom of the ion exchange column and is withdrawn from the top. Regeneration efficiency and column leakage may be improved by this process.
Water retention	Amount of water, expressed as a percent of the wet weight, retained within and on the surface of a fully swollen and drained ion exchange material.
Water softening	Exchange of sodium for the hardness in water by ion exchange.
Weak acid cation resin	Used in dealkalization and desalination systems and in conjunction with strong acid cation resins for deionization. When regenerated with acid, the resin will split alkaline salts, converting the salt to carbonic acid. This resin exhibits very high regeneration efficiency. It usually receives its exchange capacity from carboxylic groups.

Weak base anion resin	Used to remove mineral acids from solution. When regenerated with soda ash, ammonia, or caustic soda, the resin adsorbs strong acids such as HCl and H_2SO_4 from the cation bed effluent. The resin usually receives its exchange capacity from tertiary amine groups.

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