SURFACE WATER ANALYTICAL TOOL (SWAT)
VERSION 1.1
PROGRAM DESCRIPTION AND ASSUMPTIONS

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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1.0   BACKGROUND

The Surface Water Analytical Tool (SWAT) was prepared to assist the United States Environmental Protection Agency (USEPA) in the development process for the Stage 2 Disinfectants/Disinfection By-Products (D/DBP) Rule and the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). SWAT is a decision support software package designed specifically for this application. SWAT was developed jointly by Malcolm Pirnie, Inc. (MPI) and Technology Planning and Management Corporation (TPMC) with assistance and input from many Stage 2 D/DBP Rule/LT2ESWTR Technical Work Group (TWG) members. The motivation for SWAT development was the desire to have a predictive model that would use real water quality and treatment information (collected under the Information Collection Rule (ICR)) as inputs and would be calibrated using full-scale treatment data. Furthermore, the model would be constructed using a set of logical process train modification assumptions and be able to be run quickly for analysis of a wide range of regulatory scenarios. The purpose of this document is to describe the background and assumptions of SWAT and to provide guidance on program use.

1.1   Objectives
Although SWAT can be adapted for numerous uses, it was specifically designed to provide estimates of the following:
1. The distribution of treatment technologies that large surface water treatment plants nationwide would need to implement (given a pre-determined technology decision tree, approximately arranged in order of ascending cost) to comply with a given set of user-defined disinfection and DBP compliance criteria.

2. The resulting distributions of finished and/or delivered water quality parameters (especially DBPs) upon compliance with a given set of user-defined disinfection and DBP compliance criteria.

As discussed later, SWAT addresses the above items through different run modes.

2.0   PROGRAM DESCRIPTION

2.1   SWAT Structure
SWAT has four major components (as shown in Figure 2-1):
1. Database: The database which holds both inputs and outputs of the SWAT program is the ICR Auxiliary Database 8 (AUX8), a Microsoft Access® database. Inputs include raw water quality, treatment process data, and distribution system detention times. Outputs consist of the treatment technology at compliance, resulting treated water quality, and modified process train data.

2. Decision Tree Program: This element of SWAT determines what treatment technologies in the decision tree are applied to a given plant and how that

plant is modified by implementation of each technology. The decision tree program receives inputs from AUX8 and the User Interface, modifies treatment plants based on the decision tree, calls upon the Water Treatment Plant Model (see next bullet item) to calculate treated water quality parameters, and sends outputs back to the AUX8 database.

3. Water Treatment Plant Model (WTP Model): This is the main predictive component of SWAT. The WTP Model generates treated water quality predictions (of inorganic and organic parameters, including DBPs and disinfection performance) for a water treatment process train. Many of the main predictive modules of the WTP Model were calibrated using ICR data.

4. User Interface: This is a Windows™-based interface that enables the user to specify the disinfection and DBP criteria as well as numerous other assumptions for a SWAT run.
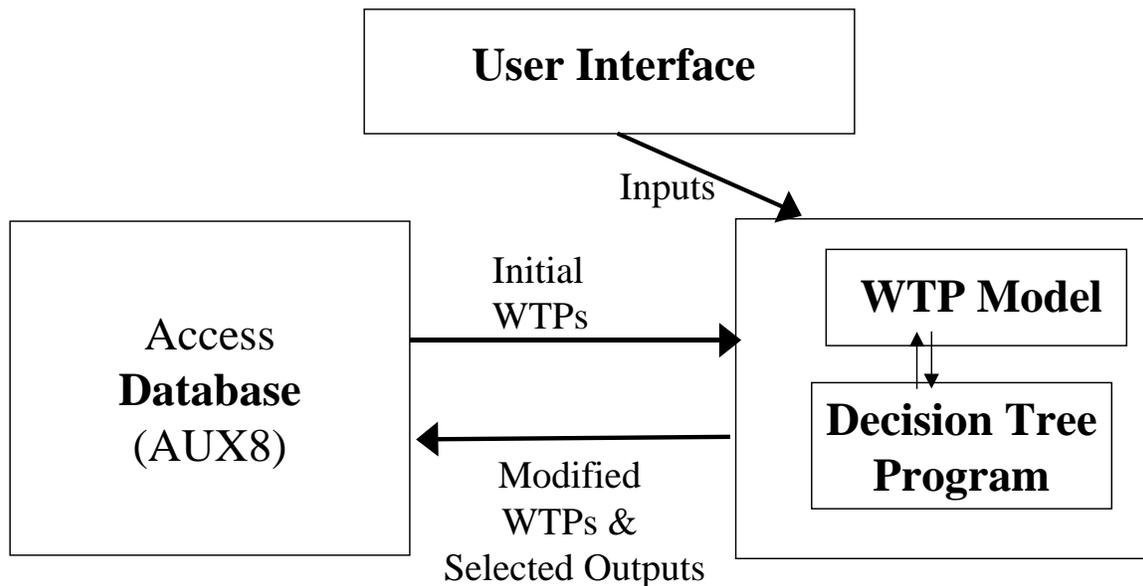

Figure 2-1: SWAT Components

2.2   SWAT Run Modes
SWAT has two primary modes of operation:
- "SMART" mode, and
- "MONSTER" mode

These two modes allow SWAT to produce the estimates identified in Section 1.1.

2.2.1 "SMART" SWAT

Figure 2-2 is a flow diagram of the logic that "SMART" SWAT uses to process a single plant (composed of multiple (up to twelve) monthly process trains, or "plant-months"). "SMART" SWAT runs this algorithm to process each "VALID" plant in AUX8 to determine the technology level for each that leads to disinfection and DBP compliance. Here, a "VALID" plant is a plant with at least one plant-month record that contains all the required inputs. "Required inputs" are all the raw water quality, process train, and distribution system data required by the WTP Model.

The logic presented in Figure 2-2 for "SMART" SWAT proceeds as follows:

1. SWAT reads the monthly raw water quality and process train data for the unmodified, initial plant from the AUX8 database.

2. SWAT calls upon the WTP model to generate treated water quality predictions for every month being processed.

3. The monthly treated water quality predictions are aggregated spatially and temporally based upon the user-specified aggregation criteria.

4. The results of this aggregation process are compared to the user-entered DBP Maximum Contaminant Levels (MCLs) to determine compliance.

5. If any aggregated DBP prediction exceeds an MCL for this plant, "SMART" SWAT determines that the plant is out of compliance and moves the plant to the next applicable technology level in the decision tree. The term "applicable" is used here because certain technologies in the decision tree are skipped for plants with certain initial technologies (Section 2.3 discusses decision tree navigation in more detail).

6. SWAT then incorporates the next technology in the decision tree into the process trains of each plant-month. SWAT sets disinfectant doses to achieve user-entered disinfection criteria or disinfection benchmark levels, if possible, and then generates, aggregates, and compares treated water quality predictions to DBP MCLs to determine compliance for the plant at this technology level.

7. This sequence continues until SWAT finds a technology level that yields compliance for this plant.

8. SWAT sends outputs back to AUX8 for a plant once it finds the complying technology level and moves on to the next plant. If compliance is not achieved at any technology level for a given plant, SWAT sends a non-compliance flag ("99") for that plant to AUX8 as the final technology level.
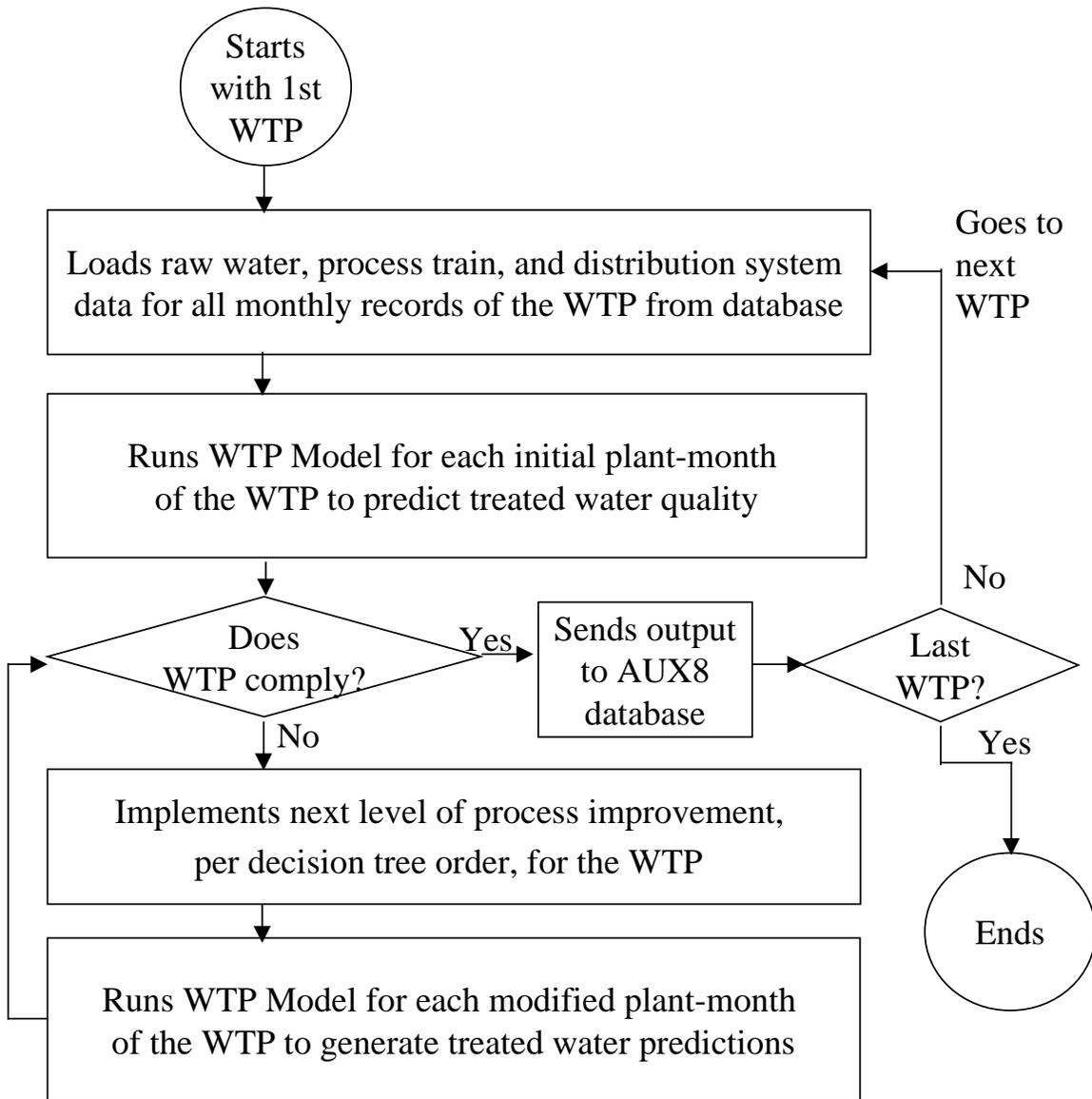
Figure 2-2: "SMART" SWAT Logic Diagram

2.2.2   "MONSTER" SWAT

"MONSTER" SWAT operates differently than "SMART" SWAT. "MONSTER" SWAT is less complex, but generates much more data. "MONSTER" SWAT generates process train and treated water quality data for every plant for every month for every applicable technology level. During a "MONSTER" SWAT run, technologies are implemented to achieve disinfection criteria, and DBP estimates are produced, but no compliance determinations are made. The "MONSTER" SWAT run mode permits increased flexibility in output data analysis by the user. This flexibility allows the user to analyze output beyond the finite number of compliance options available in "SMART" mode.

2.3 Treatment Technology Decision Tree

Figure 2-3 illustrates the process improvement decision tree used by SWAT to sequentially modify a plant's treatment train. While SWAT was programmed to use a "small systems" decision tree for plants with a design flow less than 0.2 MGD, none of the plants in AUX8 meet this criterion (the range of design flows of AUX8 plants is 5.0 to 1450 MGD). Thus, no further discussion of the small systems tree will be made beyond noting that the small systems tree is equivalent to that shown in Figure 2-3 except that all steps containing granular activated carbon were removed and steps containing ozone were made optional. Table 2-1 provides a key to the decision tree step abbreviations used in Figure 2-3.
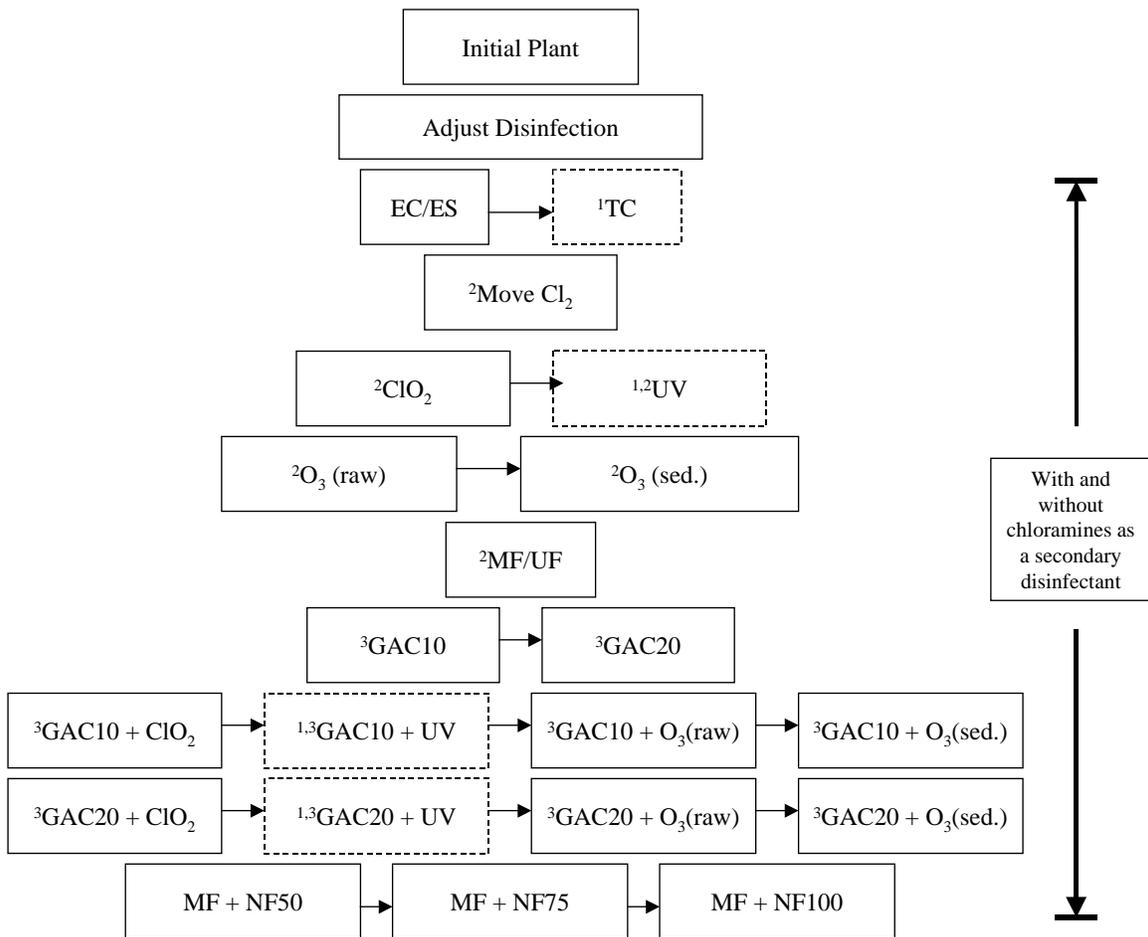
Notes:
1) Optional steps
2) With EC/ES
3) Not applicable for initial plants using precipitative softening

Figure 2-3: Treatment Technology Decision Tree

Table 2-1: Treatment Technology Decision Tree Steps – Abbreviations and Descriptions	
Abbreviation	Description
Initial Plant	Unmodified Plant
Adjust Dis.	Adjust Disinfection
EC/ES	Enhanced Coagulation / Enhanced Softening
TC	Turbo Coagulation
Move Cl_2	Move Chlorine Point
ClO_2	Chlorine Dioxide (post-filter)
UV	UV Disinfection
O_3 (raw)	Raw Water Ozone
O_3 (sed.)	Settled Water Ozone
MF/UF	Microfiltration/Ultrafiltration
GAC10	GAC (10-minute EBCT)
GAC20	GAC (20-minute EBCT)
GAC10 + ClO_2	GAC10 with Chlorine Dioxide
GAC10 + UV	GAC10 with UV Disinfection
GAC10 + O_3(raw)	GAC10 with Ozonation (raw water)
GAC10 + O_3(sed.)	GAC10 with Ozonation (settled water)
GAC20 + ClO_2	GAC20 with Chlorine Dioxide
GAC20 + UV	GAC20 with UV Disinfection
GAC20 + O_3(raw)	GAC20 with Raw Water Ozone
GAC20 + O_3(sed.)	GAC20 with Settled Water Ozone
MF + NF50	MF/UF with Split-stream (50% treated) Nanofiltration
MF + NF75	MF/UF with Split-stream (75% treated) Nanofiltration
MF + NF100	MF/UF with 100% treated by Nanofiltration

There are several important points to be made regarding the decision tree:

- The starting point is at the top of the tree, and the process improvement order is from the top row to the bottom row and from left to right in any row.

- The tree was arranged in an attempt to reflect a progression from the least costly technology to the most costly technology.

- Although only 23 steps are shown in Figure 2-3, the tree actually contains a total of 44 steps. This is because each of the last 21 technology levels shown, starting with "EC/ES," has a "with Chloramines" counterpart immediately following it. This is indicated by the side bar on Figure 2-3. Here, "with Chloramines" means the same technology, but with chloramines implemented as the secondary disinfectant.

- As indicated by the notes in Figure 2-3, depending upon the characteristics of a plant entering the decision tree, some technology steps may not be applicable for that plant. Table 2-2 contains a listing of the plant characteristics that would exclude it from application of a given technology by SWAT.

- "TC" ("Turbo Coagulation") is a technology defined by increased TOC removal through increased coagulant addition, but at a level higher than that required by enhanced coagulation. The default "Turbo Coagulation" TOC

removal matrix is a 4x3 matrix whose % TOC removal entries represent 75th percentile ICR values (25% of WTPs in a given raw water TOC-alkalinity category achieved greater than or equal to the specified TOC removal). These TOC removal criteria can be modified by the user. Furthermore, as indicated in Figure 2-3, "Turbo Coagulation" is an optional step in the tree.

- "UV" is ultraviolet disinfection. To implement "UV" in a process train, SWAT simply credits the train with the levels of inactivation specified by the user in the interface for UV technology and adjusts the existing primary disinfectant dosage(s) to provide any additional necessary CT credit. No other effects of UV are modeled. The "UV" step, along with the "GAC10+UV" and "GAC20+UV" steps, is also optional in SWAT.

Table 2-2: Characteristics of Plants that Skip a Given Decision Tree Step	
Decision Tree Step	**Plants to Skip that Step**
Initial Plant	X None
Adjust Disinfection	X None
EC/ES	X None
Turbo Coagulation	X None
Move Cl_2	X Any plant with at least one month in which chloramines are used as the primary disinfectant X Any plant with an initial technology level $\geq ClO_2$
ClO_2	X Any plant with an initial technology level $\geq O_3(raw)$, except for plants with initial technology equal to MF/UF
UV	X Any plant with an initial technology level of GAC10 or GAC20
$O_3(raw)$ and $O_3(sed.)$	X Any plant with an initial technology level $\geq$ GAC10
MF/UF	X Any plant with an initial technology level $\geq$ MF+NF50
GAC10	X Any plant with an initial technology level $\geq$ GAC20 X Any plant with an initial technology involving ozone or chlorine dioxide X Any plant with precipitative softening
GAC20	X Any plant with an initial technology level $\geq$ GAC10+ClO_2 X Any plant with an initial technology involving ozone or chlorine dioxide X Any plant with precipitative softening
GAC10+ClO_2	X Any plant with an initial technology level $\geq$ GAC20 X Any plant with an initial technology involving ozone X Any plant with precipitative softening
GAC10+UV	X Any plant with an initial technology level $\geq$ GAC20, except plants with initial technology level equal to GAC10+ClO_2 X Any plant with an initial technology involving ozone X Any plant with precipitative softening
GAC10+$O_3(raw)$ and GAC10+$O_3(sed.)$	X Any plant with an initial technology level $\geq$ GAC20+ClO_2 X Any plant with an initial technology equal to GAC20 X Any plant with precipitative softening
GAC20+ClO_2	X Any plant with an initial technology level $\geq$ GAC20+UV X Any plant with an initial technology involving ozone X Any plant with precipitative softening
Table Continued on next page	

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Table 2-2 (Continued): Characteristics of Plants that Skip a Given Decision Tree Step		
GAC20+UV	X	Any plant with an initial technology level $\geq$ GAC20+O$_3$(raw)
	X	Any plant with an initial technology involving ozone
	X	Any plant with precipitative softening
GAC20+O$_3$(raw) and GAC20+O$_3$(sed.)	X	Any plant with an initial technology level $\geq$ MF+NF50
	X	Any plant with precipitative softening
MF+NF50	X	Any plant initially with precipitative softening for which membrane softening is predicted to not achieve similar hardness removal without at least 51% of the flow treated by nanofiltration.
MF+NF50	X	Any plant initially with precipitative softening for which membrane softening is predicted to not achieve similar hardness removal without at least 51% of the flow treated by nanofiltration.
MF+NF75	X	Any plant initially with precipitative softening for which membrane softening is predicted to not achieve similar hardness removal without at least 76% of the flow treated by nanofiltration.
MF+NF100	X	None
Any "with chloramines" Step	X	Any plant initially with free chlorine as its secondary disinfectant that is not eligible for chloramine technologies due to user input selections.
Any non-"with chloramines" Step beyond "Adjust Disinfection"	X	Any plant initially with chloramines as its secondary disinfectant.

2.4 SWAT Inputs from User Interface

The SWAT program requires multiple input parameters from the graphical user interface (GUI) to execute a run. While all the required GUI inputs do have default settings, this section clarifies the significance of the GUI inputs and elucidates many of the inherent SWAT assumptions. In the GUI, inputs are grouped onto different tabs, and the discussion below follows the order of these tabs.

2.4.1 "General" Inputs Tab

Figure 2-4 contains the "General" SWAT inputs tab. This tab contains the following inputs:

- Run Mode: As noted in Section 2.2, SWAT has two primary modes of operation "MONSTER" and "SMART." There are five options shown because there is a utility run mode called "Validation" along with three variations of "SMART" mode. The "Validation" run mode was created primarily for use during calibration and validation of the WTP Model during the SWAT development process. This mode simply runs plant-months (ICR months 7 through 18 only) with their initial process configuration through the WTP Model and sends treated water quality predictions to AUX8. The different "SMART" run mode variations differ by level of output detail. The fastest mode, which does not report treated water quality or modified process train data, predicts only the complying technology level for each plant.   The other two "SMART" modes provide treated water quality and/or modified process train data for the complying technology level for each monthly record for each plant.

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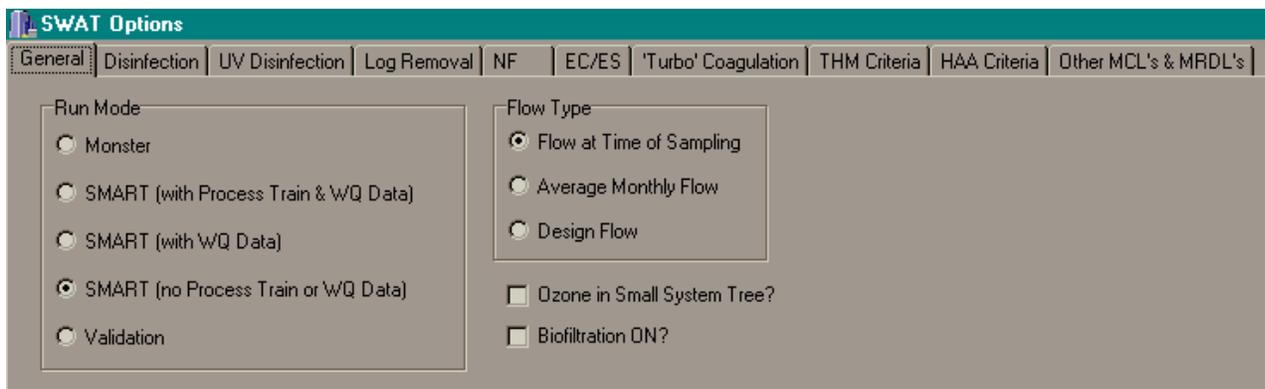
Figure 2-4: SWAT User Interface "General" Inputs Tab

- Flow Type: This input sets the type of flow assumed for process calculations in all plants in a SWAT run. The three flow options are flow at the time of ICR sampling, average monthly flow for a given ICR period, and plant design flow. The main effect of changing this input is to change treatment process detention times; however, SWAT does not change distribution system detention times in response to changes in this input.

- Biofiltration On?: This checkbox determines whether or not granular media filters (conventional or GAC media) in process trains with upstream ozonation will be eligible to achieve TOC removal through biofiltration. "Eligible" is used here because if a total chlorine residual or ozone residual greater than 0.1 mg/L is present in the filter influent, SWAT assumes that no TOC will be removed by biofiltration, independent of this input parameter's setting.

- Ozone in Small Systems Tree?: This checkbox determines whether or not ozone process improvements will be included in the small system decision tree.

2.4.2 "Disinfection" Inputs Tab

Figure 2-5 contains the "Disinfection" SWAT inputs tab. This tab contains inputs that govern how SWAT sets disinfectant doses to as it makes process improvements to plants at the various technology levels in the decision tree. This tab contains the following inputs:

- Required Log Removal plus Inactivation: These parameters set the minimum total level of disinfection for *Giardia*, viruses, and *Cryptosporidium* that must be achieved in every month for a plant to be in compliance at a given technology level. These total disinfection levels must be achieved through a combination of physical removal credits and/or inactivation credits.

- Required Minimum Log Inactivation: These parameters provide the user with the flexibility to set minimum chemical inactivation requirements above any

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physical removal credit. In SWAT, chemical inactivation is achieved through the use of free chlorine, chloramines, ozone, chlorine dioxide, and/or UV.

Figure 2-5: SWAT User Interface "Disinfection" Inputs Tab

- Disinfection Benchmarking Method: These inputs are used in conjunction with the "Required Log Removal plus Inactivation" and "Required Minimum Log Inactivation" criteria to determine the applicable disinfection requirements for a given plant. If "Benchmarking OFF" is selected, then SWAT will size disinfectant doses to meet the most stringent of the "Required Log Removal plus Inactivation" and "Required Minimum Log Inactivation" criteria. If "Benchmarking ON" is selected, SWAT determines the minimum monthly level of log removal plus inactivation for each pathogen for each initial plant and sets these as the log removal plus inactivation requirements for that plant (if these requirements are more stringent than the criteria entered by the user under "Required Log Removal plus Inactivation"). Two entry boxes are provided for entering maximum benchmarks for *Giardia* and viruses. Thus, if the lowest monthly level of virus inactivation achieved by a given plant was 35.0 logs, and a 9.0-log maximum virus benchmark were set, a 9.0-log virus inactivation plus removal requirement would be used for that plant. This example assumes that the virus log removal plus log inactivation and minimum log inactivation criteria were both set less than or equal to 9.0 logs.

- *Cryptosporidium* CT Multiplier: This checkbox provides the user with the ability to test the sensitivity of SWAT results to the assumed *Cryptosporidium* inactivation performance of chlorine dioxide. The determination of a *Cryptosporidium* CT (Concentration × Time) table for chlorine dioxide is a focus of current research. Such a CT table was not available at the time of SWAT development. Thus, SWAT includes an input parameter that represents a multiplier to apply to the $CT_{required}$ for *Giardia* inactivation by chlorine dioxide to determine the $CT_{required}$ for an equivalent level of *Cryptosporidium* inactivation with chlorine dioxide. The default value is set as 7.5, which means that 7.5 times the $CT_{required}$ for *Giardia* inactivation is required for an equivalent amount *Cryptosporidium* inactivation. The 7.5 value may not be conservative. Recent research results, incorporated into the WTP model and SWAT, indicated an approximate range of 7 to 22 for a similar multiplier for ozone, depending on the targeted level of inactivation and water temperature.

- Method to Determine Which WTPs with Free Chlorine in DS to Convert to Chloramines: This set of inputs on the disinfection tab addresses the issue of secondary disinfection using chloramines. As discussed in Section 2.3, every technology starting with the "EC/ES" step in the decision tree has a "with Chloramines" counterpart. These decision tree steps include chloramination as secondary disinfection and apply to any initial plant classified as a plant already using chloramines in the distribution system (DS) or to some or all of the plants classified as initially using free chlorine in the DS. Because some plants, whose initial configuration includes free chlorine in the DS, will likely not be considered for a chloramines conversion for reasons outside of the range of consideration of SWAT, the program provides several options to determine which plants with free chlorine in the DS will skip the "with Chloramines" steps. These options for determining which plants currently using free chlorine in the DS are eligible to use chloramines are:
  - All plants using free chlorine in the DS are eligible to switch to chloramines.
  - No plants using free chlorine in the DS are eligible to switch to chloramines.
  - Some plants using free chlorine in the DS are eligible to switch to chloramines. Furthermore, the determination of which plants using free chlorine plan can switch is random and governed by an input percentage. The percentage sets the probability that a given plant is eligible to switch to chloramines. Thus, the actual fraction of free chlorine plants determined to be eligible to switch to chloramines for a given SWAT run will not necessarily be equal to the input percentage; however, for a large number of plants, the actual fraction is likely to approach the input value. Many SWAT runs performed by the TWG used this random assignment option with an input value of 77% based upon an independent survey of utilities.

- Note that there are two additional options that are not active shown on the "Disinfection" inputs tab for determining which plants are eligible to implement chloramines.

Also related to chloramines is a checkbox that is used to determine in how many months chloramines is implemented for a plant undergoing a "with Chloramines" process modification step. When checked, SWAT performs the following:
- Chloramines are implemented as the DS disinfectant in all months (that do not have chloramines already) for any plants initially classified as using free chlorine in the DS that are eligible to switch to chloramines.
- Chloramines are implemented as the DS disinfectant in all months (that do not have chloramines already) for any plants initially classified as "chloramine" plants.

When this box is not checked, SWAT performs the following:
- Chloramines are implemented as the DS disinfectant in all months (that do not have chloramines already) except the warmest month for any plants initially classified as "free chlorine" (in DS) plants that are eligible to switch to chloramines.
- No change to the secondary disinfectant type is made in any month for those plants characterized initially as "chloramine" (in DS) plants.

Two final notes should be made regarding chloramines in the DS:
- SWAT reads the secondary disinfectant classification of an initial plant from the AUX 8 database. In AUX8 an initial plant is classified as using chloramines in the DS if the percentage of "VALID" monthly records in which chloramines are used is greater than or equal to 50%. Otherwise, the initial plant is considered a "free chlorine" (in DS) plant.
- Initial plants determined to use chloramines in the DS proceed through the following decision tree steps:
  - "Initial Plant"
  - "Adjust Disinfection"
  - "EC/ES with Chloramines"
  - "with Chloramines" steps

  That is, plants determined to initially use chloramines in the DS are never considered for a change to free chlorine as the secondary disinfectant.

- WTPs Assumed Able to Make Clearwell Baffling Improvements: SWAT will attempt to meet disinfection and residual disinfectant goals in a plant by baffling any existing clearwell(s), if necessary, in the following process improvement steps (and their "with Chloramines" counterparts):
  - "Move Cl_2"
  - "MF/UF"
  - "GAC10," "GAC20"
  - "GAC10+UV," "GAC20+UV"

- "MF+NF50," "MF+NF75," "MF+NF100"

These decision tree steps have the common characteristic that chlorine is used for primary disinfection only toward the end of the modified process train prior to any clearwell(s). At that location in the process train, there must be both enough detention time (T_{10}) in the clearwell(s) to achieve inactivation goals and enough time (T_{50}) to allow chlorine residual to decay sufficiently to achieve residual disinfectant goals. If there is not, SWAT may first implement baffling before considering augmenting the plant's clearwell capacity. When implementing baffling, SWAT sets the $T_{10}/T_{theoretical}$ value of a clearwell equal to its $T_{50}/T_{theoretical}$ value (up to a maximum value of 0.80). However, for some plants, in which site constraints may make baffling an expensive proposition, this assumption may not be valid within the order of the decision tree. That is, the complexities associated with baffling the clearwell in some plants would be sufficiently cost-prohibitive to cause the step that includes this modification to be more costly than steps further down in the decision tree. Thus, SWAT provides an input that determines the likelihood of any given plant to be able to baffle its clearwell with reasonable cost. Plants are then assigned a baffling eligibility status determined randomly based on the inputted percentage (similar to the method in which "free chlorine" (in DS) plants are assigned an eligibility status to switch to chloramines in the DS).

This input parameter was set to 90% in many SWAT runs performed by the TWG.

2.4.3 "UV Disinfection" Inputs Tab
Figure 2-6 contains the "UV Disinfection" SWAT inputs tab. This tab contains the following inputs related to implementation of decision tree steps containing UV technology:
- UV disinfection step included in decision tree?: If this box is checked, the following technology steps and their "with Chloramines" counterparts will be included in the decision tree:
  - "UV"
  - "GAC10+UV"
  - "GAC20+UV"

  If this box in not checked, these three technologies and their "with Chloramines" counterparts are excluded from the decision tree.

- Inactivation by UV: This set of inputs establishes the level of inactivation credit assigned to the UV process for *Giardia*, viruses and *Cryptosporidium*. Since these are inactivation credits, the credits count toward any "Minimum Log Inactivation Requirements" set by the user on the "Disinfection" input tab.
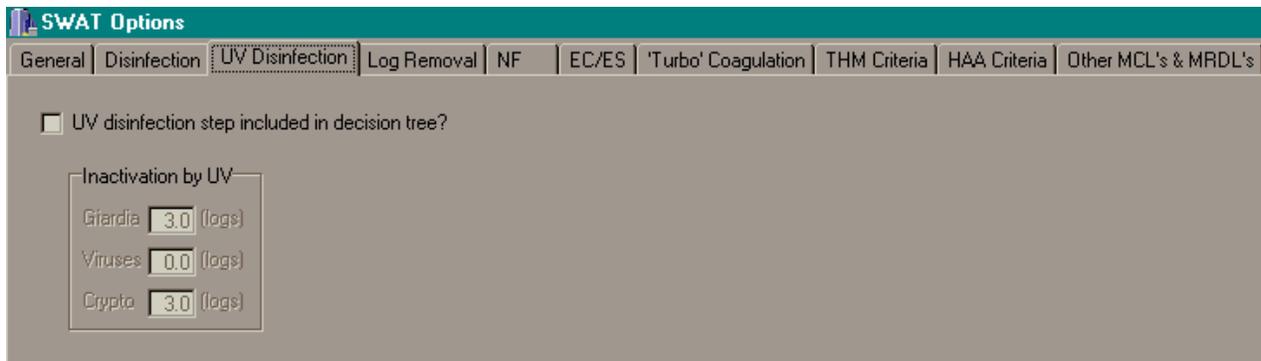
Figure 2-6: SWAT User Interface "UV Disinfection" Inputs Tab

2.4.4 "Log Removal" Inputs Tab
Figure 2-7 shows the "Log Removal" SWAT inputs tab. This tab contains the following inputs related to the physical removal credits assigned to various treatment processes:

- *Giardia* Log Removal (logs): This set of inputs establishes the physical removal credits (in logs) for *Giardia* assigned by SWAT to microfiltration/ultrafiltration, nanofiltration, sedimentation, and (granular media) filtration processes.

- Virus Log Removal (logs): This set of inputs establishes the physical removal credits (in logs) for virus assigned by SWAT to microfiltration/ultrafiltration, nanofiltration, sedimentation, and (granular media) filtration processes.

- *Cryptosporidium* Log Removal (logs): This set of inputs establishes the physical removal credits (in logs) for *Cryptosporidium* assigned by SWAT to microfiltration/ultrafiltration, nanofiltration, sedimentation, and (granular media) filtration processes.
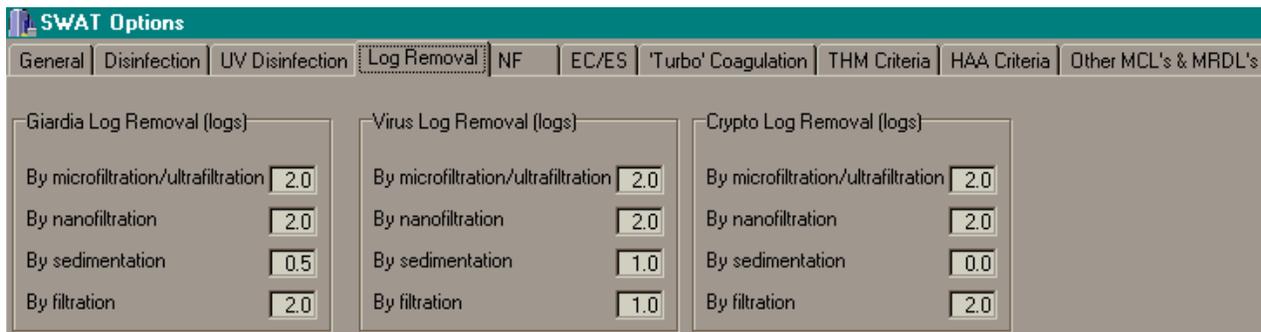

Figure 2-7: SWAT User Interface "Log Removal" Inputs Tab

Sedimentation and filtration default values were set to achieve SWTR Guidance Manual values for well-operated conventional and direct filtration plants. It also should be noted that SWAT adds the credits for these individual processes to determine the

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overall log removal credit for the entire process train with respect to each pathogen. However, SWAT does not count log removal credits multiple times for the same treatment process repeated multiple within a process train. For example, if a process train happens to have two sedimentation basins, SWAT does not grant twice the sedimentation basin log removal credit when calculating the overall process train log removal credit.

2.4.5 "NF" Inputs Tab

Figure 2-8 shows the "NF" SWAT inputs tab, which contains the following inputs related to the implementation of the nanofiltration process in SWAT:

- Nanofiltration Removals: Because the WTP Model used in SWAT lacks reliable algorithms for the removal of TOC, UV_{254}, and bromide by nanofiltration, these parameters have been set as inputs. While default values were set based on typical performance, subsequent work by the TWG indicated the following median values from ICR Treatment Studies data:
  - TOC Removal = 92%
  - UVA Removal = 87%
  - Bromide Removal = 78%

- Molecular Weight Cut-off and Recovery: These inputs are both used in WTP Model calculations of hardness and alkalinity removal.
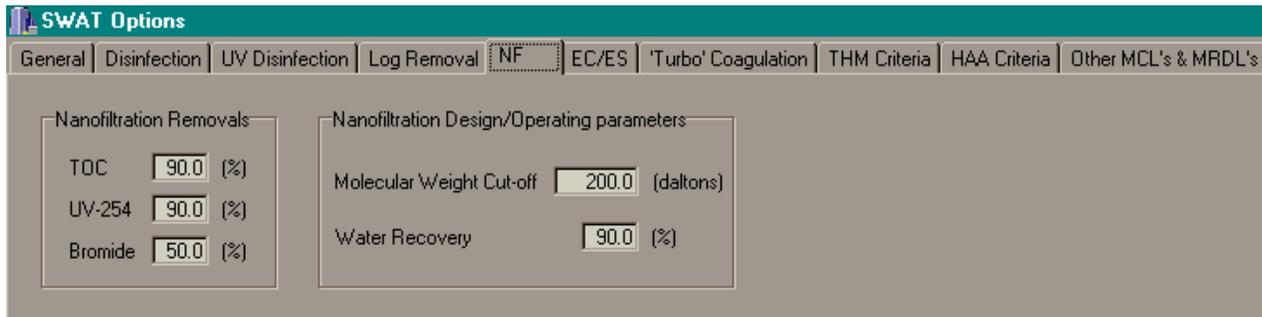
Figure 2-8: SWAT User Interface "Nanofiltration" Inputs Tab

2.4.6 "EC/ES" Inputs Tab

This input tab (Figure 2-9) allows the SWAT user to change default parameters related to enhanced coagulation/enhanced softening. The tab contains inputs for raw water TOC, raw water SUVA (calculated as UVA/TOC×100 in SWAT), and finished water TOC alternative compliance criteria as well as the nine elements of the 3×3 TOC removal matrix. Section 2.7.3 provides a more detailed discussion of SWAT EC/ES implementation.
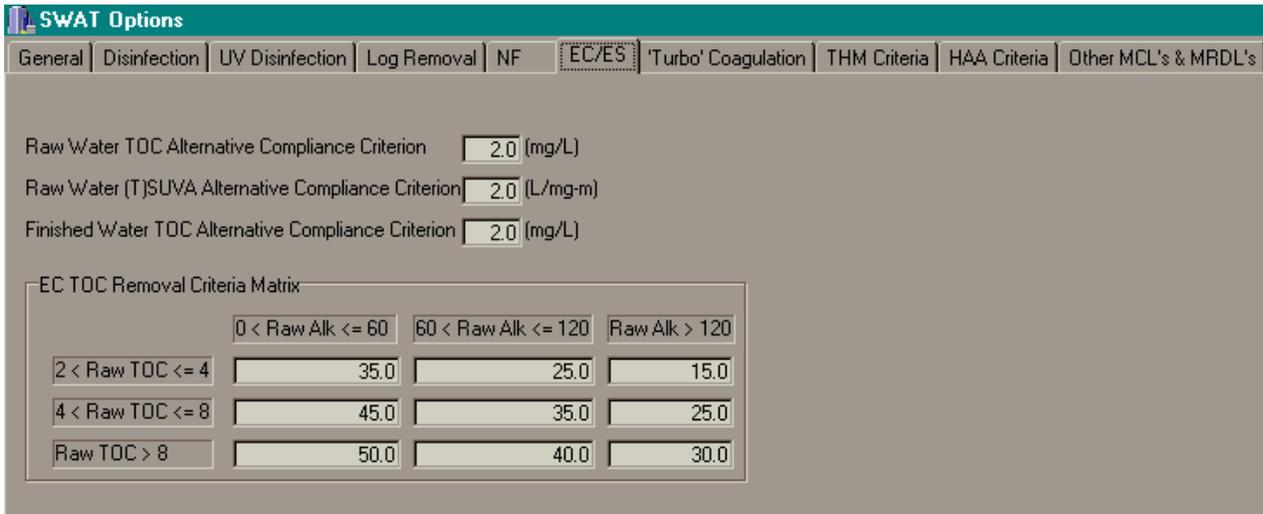
Figure 2-9: SWAT Interface "Enhanced Coagulation/Enhanced Softening" Tab

2.4.7   "Turbo Coagulation" Inputs Tab

Section 2.3 introduced the "Turbo Coagulation" (TC) decision tree step. This inputs tab (Figure 2-10) contains the following user inputs for SWAT implementation of this technology:

- <u>Include 'Turbo' Coagulation in the decision tree for this run</u>: When this box is checked the "Turbo Coagulation" step and its "with Chloramines" counterpart are included in the SWAT technology decision tree. When unchecked, these steps are excluded.
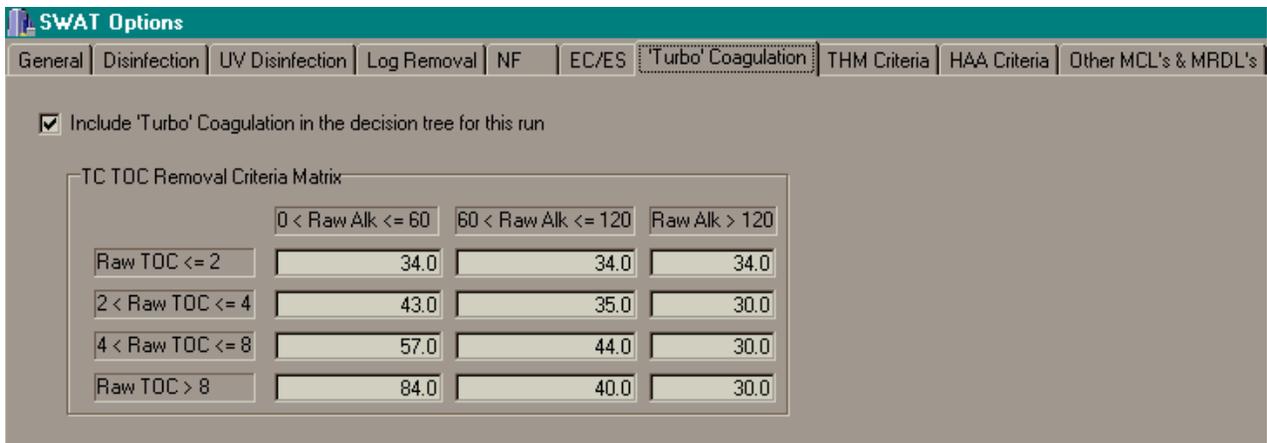
Figure 2-10: SWAT User Interface "Turbo Coagulation" Inputs Tab

- TC TOC Removal Criteria Matrix: This input defines the TOC removal goals that SWAT attempts to achieve in plants at the "Turbo Coagulation" step in similar fashion to the "EC/ES" step. Section 2.7.4 provides a more detailed discussion of SWAT TC implementation.

2.4.8 "THM Criteria" Inputs Tab

Figure 2-11 shows the "THM Criteria" SWAT inputs tab on which the user can design compliance criteria related to trihalomethanes for a "SMART" SWAT run. Because DBP compliance criteria are not used in a "MONSTER" SWAT run, these inputs are not relevant to this type of run. This tab contains the following inputs:

- MCLs: This group of inputs permits the SWAT user to specify the THMs to regulate in a given "SMART" SWAT run and the corresponding maximum contaminant levels (MCLs), expressed in μg/L. SWAT provides the option to set MCLs for up to two aggregate trihalomethane measures and each of the four THM species. It should be noted that SWAT predicts TTHM and the individual species (bromoform, dibromochloromethane (DBCM), and bromodichloromethane (BDCM)) with separate algorithms. SWAT calculates THM3 as the sum of the predictions of bromoform, DBCM, and BDCM.

- Temporal Aggregation Methods: This group of inputs allows the user to specify the temporal basis for determining compliance with the THM MCLs. For each THM, the user may select only one of the following three temporal aggregation alternatives:
  - *Annual Average*: SWAT averages the THM predictions at the selected location (see "Spatial Aggregation Methods" below) for all monthly records for a given plant and compares the average value to the selected MCL value. Note that the number of months that are included in the average is equal to the number of "VALID" plant-months (from 1 to 12) for a given plant.
  - *Quarterly Average*: SWAT averages the THM predictions at the selected location for all monthly records (up to 3) for each quarter for a given plant and compares each of the quarterly averages to the MCL. If any of the quarterly averages is greater than the MCL, the plant is out of compliance.
  - *Percentile Basis*: SWAT orders all the monthly THM predictions at the selected location for a given plant and compares the nth percentile THM value to the MCL, where "n" is the user-entered percentile. Setting "n" equal to 100 represents a "not-to-exceed" criterion.

- Spatial Aggregation Methods: This set of inputs allows the SWAT user to specify the sampling location, or representative sampling location, that THM concentration predictions are to be taken for use in subsequent temporal aggregation and compliance determinations. The SWAT user must select one of three locations:
  - *Plant Effluent*: SWAT uses THM predictions at the finished water location.

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- *Distribution System Average* (DS_AVG): SWAT uses THM predictions from the DS_AVG location. In the AUX8 database, the DS_AVG location is defined by a distribution system detention time that is the average of the values reported by a utility for the ICR locations known as "AVG1," "AVG2," "DSE," and "MAX."
- *Distribution System Maximum* (DS_MAX): SWAT uses THM predictions from the DS_MAX location. In the AUX8 database, the DS_AVG location is defined by a distribution system detention time that is the maximum of the values reported by a utility for the ICR locations known as "AVG1," "AVG2," "DSE," and "MAX."
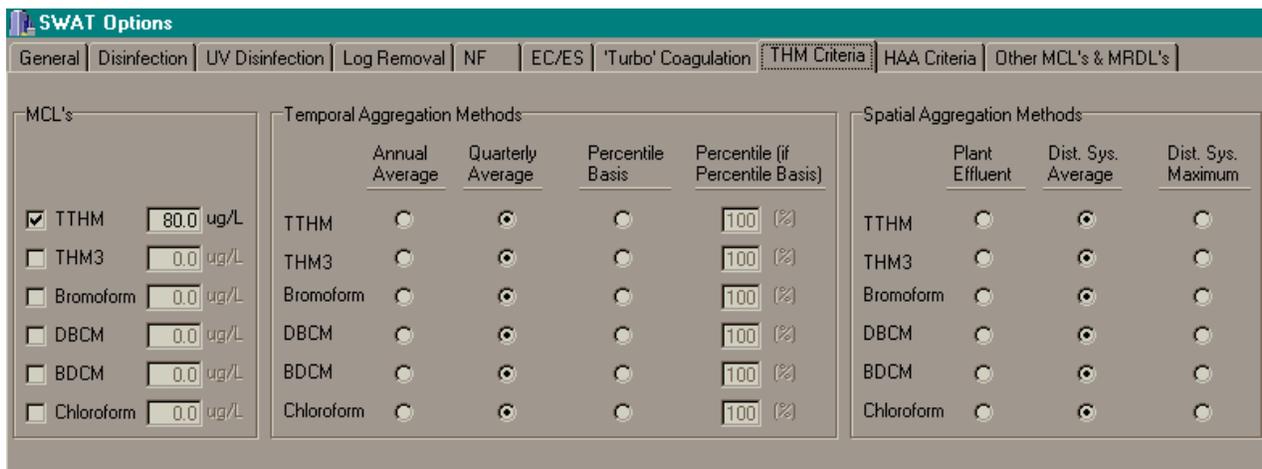
Figure 2-11: SWAT User Interface "THM Criteria" Inputs Tab

2.4.9 "HAA Criteria" Inputs Tab

Figure 2-12 shows the "HAA Criteria" SWAT inputs tab on which the user can design compliance criteria related to haloacetic acids for a "SMART" SWAT run. These inputs, like those on the "THM Criteria" tab, are not relevant to a "MONSTER" SWAT run. This tab has a similar design as that of the "THM Criteria" tab; however, the following clarifications are warranted:

- MCLs Input Box:
  - SWAT provides the user with the option to establish MCLs for the following individual HAAs (and uses separate algorithms to predict the concentrations of each):
    - MCAA (monochloroacetic acid)
    - DCAA (dichloroacetic acid)
    - TCAA (trichloroacetic acid)
    - MBAA (monobromoacetic acid)
    - DBAA (dibromoacetic acid)
    - BCAA (bromochloroacetic acid)
  - SWAT also provides the user with the option of establishing MCLs for the following aggregate HAA parameters (and uses separate algorithms to predict the values of each):

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- HAA5 (which includes MCAA, MBAA, DCAA, TCAA, and DBAA)
- HAA6 (which includes BCAA along with the HAA5 species)

- SWAT further provides the user with the option of establishing an MCL for HAA9. SWAT predicts HAA9 by first predicting the values of bromodichloroacetic acid (BDCAA), dibromochloroacetic acid (DBCAA), and tribromoacetic acid (TBAA). SWAT predicts BDCAA, DBCAA, and TBAA concentrations based on relationships using predicted values of other HAA and THM species. Finally, SWAT adds the predicted BDCAA, DBCAA, and TBAA values to the predicted HAA6 value to generate a predicted value for HAA9.

The following points clarify the above discussion of SWAT THM and HAA predictions:

- Plant-monthly predictions of bromoform, chloroform, BDCM, and DBCM may not (and are likely to not) sum to the predicted value of TTHMs.
- Plant-monthly predictions of MCAA, MBAA, DCAA, TCAA, and DBAA may not (and are likely to not) sum to the predicted value of HAA5.
- Plant-monthly predictions of MCAA, MBAA, DCAA, TCAA, DBAA, and BCAA may not (and are likely to not) sum to the predicted value of HAA6.
- The prediction of HAA5 may exceed the prediction of HAA6 in a limited number of plant-months.
- The predicted value of HAA9 will always be greater than or equal to the predicted value of HAA6.

Figure 2-12: SWAT User Interface "HAA Criteria" Inputs Tab

2.4.10 "Other MCLs and MRDLs" Inputs Tab

Figure 2-13 shows the "Other MCLs and MRDLs" SWAT inputs tab. This input tab is designed similarly to the "THM Criteria" and "HAA Criteria" input tabs. It allows the user to set compliance criteria for the following parameters:

- DBP MCLs:
  - Total organic halides (TOX), in µg/L as Cl
  - Bromate, in µg/L
  - Chlorite, in mg/L

- Maximum Residual Disinfectant Levels (MRDLs):
  - Free chlorine residual, in mg/L
  - Chloramine residual, in mg/L as total chlorine

It is important to note here that while the MCLs on this input tab are relevant only to "SMART" SWAT runs, the MRDLs are relevant to both "SMART" and "MONSTER" SWAT runs. In both types of runs, SWAT checks to make sure that MRDLs are met in any decision tree step where it is installing a free chlorine dose prior to a clearwell at the end of a process train for the purpose of achieving pathogen inactivation criteria. In an attempt to meet both inactivation and MRDLs, SWAT may baffle existing clearwells and/or add a new one to provide sufficient contact time at a given plant. SWAT performs these operations in the following decision tree steps (and their "with Chloramines" counterparts; these steps are the same as those listed in Section 2.4.2, which deals with clearwell baffling):

- "Move Cl_2"
- "MF/UF"
- "GAC10," "GAC20"
- "GAC10+UV," "GAC20+UV"
- "MF+NF50," "MF+NF75," "MF+NF100"

Figure 2-13: SWAT User Interface "Other MCLs and MRDLs" Inputs Tab

2.5   Inputs from the AUX8 Database

Section 2.4 presented SWAT user inputs entered through the SWAT GUI. This section discusses inputs to the SWAT program stored in the AUX8 database and not intended for modification by the SWAT user. In addition to the raw water quality and unit process data in the AUX8 database that is required by the WTP Model, SWAT uses a number of other inputs from the AUX8 database. These inputs are parameters that describe a process train or a group of process trains and do not change from run to run. This section describes these inputs and their use in SWAT. The end of this section also describes "estimated" SWAT inputs.

2.5.1 Plant-level Inputs

The inputs in this section are at the plant level, and their values in AUX8 were set by queries employed during the extraction of that database from AUX1. The plant-level inputs are based on analysis of the monthly process trains (plant-months) for a given plant. The AUX8 table and field names are indicated in parentheses.

- Initial Technology Level (TUXWTP : INITECH): This input describes the initial technology level of each plant so that SWAT knows to skip any irrelevant decision tree steps. This technology level determination actually is made for each monthly process train first, and the plant-wide initial technology level then is set equal to the maximum monthly technology level of the "VALID" plant-months (where "VALID" means that TUXPLT:MODE_SWAT = "VALID"). Some plants implemented ozonation in the middle of the ICR; for these plants, SWAT installs a raw water ozonation system during the initial decision tree step for the months that did not have ozone initially.

- System Size (TUXWTP : LARGEFLG): This is a yes/no determination, where "Yes" indicates a plant with a design flow greater than or equal to 0.2 MGD. "Yes" indicates to SWAT that the large system decision tree is to be used for this plant. As discussed in Section 2.3, none of the plants in AUX8 have design flow rates less than 0.2 MGD, so this field contains a "Yes" for all plants.

- Typical DS Disinfectant Type (TUXWTP : MOSTDSCLM): This input determines whether the typical secondary disinfectant used by a given plant is chloramines or free chlorine. If greater than or equal to 50% of the "VALID" monthly records indicate chloramines in the DS (TUXPLTRUN:DS_DIS = CLM), then the initial plant is described as typically using chloramines in the distribution system. Section 2.4.2 describes how SWAT uses this determination.

- All Months with Chloramines as DS Disinfectant? (TUXWTP : ALLDSCLM): This is a yes/no determination, where "yes" indicates that chloramines was the secondary disinfectant (TUXPLTRUN:DS_DIS = CLM) used in all "VALID" plant-months for a given plant. If this parameter is "yes," a plant with chloramines in the DS would not require changes to DS disinfectant type in any month during a "with Chloramines" process modification step, when the "All Months Go to Chloramines" checkbox is selected on the "Disinfection" inputs tab (see Section 2.3).

2.5.2 Plant-month-level Inputs

The inputs in this section are plant-month-level, and their values in AUX8 were determined based on queries employed during the AUX8 extraction process that consider data relevant to a single process train and associated observed water quality. The utility of having these determinations made during the database extraction process is that SWAT does not then need to make them for each and every run. The AUX8 table and field names are indicated in parentheses. In addition to the plant-month-level inputs shown below, there are all of the raw water quality and process train inputs required to run the WTP Model.

- EC/ES Required Based Upon Observed Finished Water TOC? (TUXPLTRUN:ECRQ_FWT): This input tells SWAT whether or not this plant-month meets the 2.0 mg/L default EC/ES finished water TOC alternative compliance criterion (ACC) based on observed data. A value of "0" indicates that it did meet this ACC. "1" indicates it did not. "2" indicates no relevant observed data are available (SWAT then makes the ACC determination based on predicted TOC).

- EC/ES Required Based Upon Observed Raw Water TOC or SUVA? (TUXPLTRUN:ECRQ_RAW): This is an input similar to the above, but it applies to raw water TOC and raw water SUVA. However, there is no "2" option since any month to be run by SWAT must have observed raw water TOC and UVA data.

- TOC Removal Ratio (TUXPLTRUN:TOC_REM): This is a calculation of the observed TOC removal ratio (= % TOC removal observed / default % TOC removal required by EC/ES) for a given plant month. A value of "-1" is inputted if no relevant treated water TOC data is available. If a value of "-1" is present in this field in AUX8, or if any default EC/ES TOC removal criteria are overridden in the user interface, SWAT will calculate this ratio based on predicted TOC values.

- EC/ES Compliance Ratio (TUXPLTRUN:EC_CR): This parameter simply contains a 1.0 or a 0.0 upon input. Any process train without a sedimentation basin or with a GAC unit process gets a 1.0, indicating to SWAT that EC/ES requirements are met for this month. Any other process trains get a value of 0.0, which indicates to SWAT that it must calculate the compliance ratio based upon TOC removal or ACC determinations.

- Observed Plant Effluent pH (TUXPLTRUN:PH_FW): In all process modification steps, SWAT sets the treated water pH to the value of the observed treated water pH in the initial plant-month. This input parameter represents the target value. If no relevant observed data are available, SWAT uses the predicted pH for the initial plant-month configuration as the target.

- Primary Disinfectant Type (TUXPLTRUN: WTP_DIS): This input parameter describes the type of primary disinfection scheme used in an initial plant-month. The inputted value indicates free chlorine ("CL2"), free chlorine and chloramines ("CL2_CLM"), chloramines ("CLM"), chlorine dioxide ("CLX"), or ozone ("O3"). SWAT uses this input to identify the primary disinfectant application point in the initial process train.

- Secondary Disinfectant Type (TUXPLTRUN: DS_DIS): This input parameter describes the type of secondary disinfectant used in an initial plant-month as either free chlorine ("CL2") or chloramines ("CLM").

- Is There an Effluent Chlorine Point? (TUXPLTRUN: EFF_CL2): This is a yes/no input. "Yes" indicates that there is a chlorine or hypochlorite dose in the initial process train following all unit processes with volumes; otherwise, it is set as "No." If a process train has a "No" for this input, such a chlorine dose will be added to the initial process train and will be used in process modification steps to achieve the target effluent total chlorine residual.

- Hottest Month? (TUXPLTRUN:HOT_MNT): This is a yes/no input. "Yes" indicates that the observed raw water temperature in this month was warmer than all the other VALID months within the twelve-month range (sample periods 7 through 18) being analyzed for this plant. Section 2.4.2 explains how SWAT uses this information along with selections made on the "Disinfection" inputs tab when implementing "with Chloramines" decision tree steps.

- Period Number (TUXPLTRUN:SAMP_PER): This input holds the ICR period (month) number to which this plant-month belongs. Period 1 is July 1997, and period 18 is December 1998. SWAT uses this information to calculate the quarter to which each plant-month belongs to facilitate quarterly average DBP compliance determinations.

2.5.3   *Estimated SWAT Inputs*
In the AUX1 database (from which the AUX8 database is extracted) there is a substantial amount of missing raw water quality data that are required to run SWAT. These data are missing because some participating ICR utilities did not report the information or the analytical results failed quality control checks and were not included in the database. To increase the number of plant-months that SWAT could process, it was determined that several raw water quality parameters should be estimated to more fully populate the AUX8 database upon its extraction from AUX1. The following points describe how these parameters were estimated:

- Turbidity: This parameter is required to run the WTP Model, but is not used in any of the calculations pertinent to SWAT; thus, any monthly turbidity input values missing in AUX1 were simply filled-in as "999999.0" during extraction of

AUX8.

- pH, calcium hardness, total hardness, alkalinity, and ammonia: Missing monthly values for these parameters for a given plant were estimated based on the average of the values that were reported in AUX1 for the other months for that plant.

- TOC and UVA: These parameters were determined to be too critical to estimate each separately based on an average of other monthly values. Thus, missing monthly values for TOC and UVA were estimated only if a value for the other existed for that month. If the other value did exist, the missing value was estimated based on the value of the other and the average ratio of the UVA to TOC for the months in which both values existed for that plant.

- Temperature: Missing monthly raw water temperature values were estimated by extracting observed temperature data from downstream processes in the same plant-month.

2.6   General Process Modification Concepts
This section presents several important concepts that are generally applicable to all steps in the SWAT decision tree. Section 2.7 defines specific assumptions to the different decision tree steps to illustrate how SWAT changes process trains when it upgrades the treatment technology of a plant.

2.6.1   Primary Disinfection Achievement
A key SWAT task applicable to all decision tree steps is the sizing of the primary disinfectant dosage(s) to achieve disinfection compliance. In all decision tree steps except for "Adjust Disinfection," "EC/ES," "Turbo Coagulation," "UV Disinfection," "MF/UF" and their "with Chloramines" counterparts, there is only a single primary disinfectant dose to size. In these single primary disinfectant dose cases, the logic below applies to the sizing of that single dose. For the decision tree steps noted above, SWAT also adjusts the dose of an existing additional chlorine dose (if one exists) in the process train. That is, if a process train has two chlorine doses contributing to CT, the second dose would also be adjusted, if necessary. Here, "if necessary" means that if the first chlorine dose is adjusted to zero and still there is more disinfection than that required, the second chlorine dose would also be modified downward until disinfection requirements were just met. It should be noted here that "disinfection requirements" take into account disinfection benchmarking, if benchmarking is selected by the user for a given run.
Section 2.4.2 discusses how SWAT sets the disinfection requirements for a plant using "Required Log Removal plus Log Inactivation," "Required Minimum Log Inactivation" and "Disinfection Benchmarking Method" inputs from the user interface along with the predicted disinfection performance in all the initial months for that plant. Once these requirements are established, SWAT performs the following to determine the appropriate primary disinfectant dose in a process train:
- For each pathogen, physical log removal credit is subtracted from total disinfection required to calculate inactivation required.

- For each pathogen, the above-calculated "inactivation required" value is compared to the minimum log inactivation required criterion, and the maximum of the two values becomes the final log inactivation required value.

- $CT_{required}$ values are calculated based on final log inactivation required values, disinfectant type, temperature, and other water quality parameters.

- A binary search routine is then employed to determine the primary disinfectant dose that produces $CT_{achieved}$ values such that the *minimum* CT Ratio (CT Ratio = $CT_{achieved}$ / $CT_{required}$) for the three pathogens is between 1.0 and 1.2. The pathogen for which the CT ratio is a minimum is referred to as the "limiting pathogen" in this document.

2.6.2 Secondary Disinfection Achievement

Another critical SWAT task is to set the secondary disinfectant dosages in process trains for all decision tree steps. SWAT handles secondary disinfectant dose setting in the following manner:

- SWAT receives the type of secondary disinfectant (free chlorine or chloramines) as an input parameter from AUX8.

- In the "Initial Plant" decision tree step, SWAT predicts the magnitude (total chlorine residual) of the secondary disinfectant at the plant effluent in each process train and sets this as the target to be achieved in subsequent decision tree steps. However, there are two exceptions to this rule:
  - If the predicted residual is greater than the applicable MRDL, the target is set as 0.99 times the MRDL.
  - If the predicted residual is less than 0.1 mg/L, the target is set as 0.1 mg/L.

- A pair of chlorine and ammonia doses just upstream of the plant effluent is inserted in the process train, if not already existing in the initial plant-month configuration.

- These end-of-train doses are modified in subsequent decision tree steps to achieve the target residual concentration and type (free or combined chlorine).

- An exception to the end-of-train placement of these doses is during ozonation steps where SWAT configures the process train to include free chlorine contact time following biofiltration. In these cases, the doses used to achieve the target residual may not occur at the end of the train (see Section 2.7.8).

2.6.3 pH Matching

Because distribution systems are typically sensitive to changes in delivered water pH, SWAT assumes that during process modification steps, finished water pH in the modified process train is set to a target value that reflects the finished water pH in the initial plant configuration. This target value is taken as the observed value for the initial

plant, or the predicted value, if no observed value exists in the AUX8 database. SWAT does not achieve the target effluent pH by adding an acid or caustic dose prior to the plant effluent, it just assumes that such a dose would be added and sets the pH at the target value. Thus, no such chemical additions for this purpose appear in SWAT output.

2.7   Process Modification Step Details

Each process modification step in the SWAT decision tree consists of a set of assumptions regarding how a certain treatment technology is implemented in a process train. Of course, the technology has to be implemented in all the multiple monthly process trains (plant-months) that constitute a plant. This section summarizes the assumptions used in SWAT decision tree steps.

2.7.1   "Initial Plant" Step

The "Initial Plant" decision tree step serves two main purposes:

- Predict the performance of initial plant configurations (without significant treatment process modifications)

- Prepare the plant for processing in later decision tree steps.

Most of the work that SWAT performs during this step is associated with the latter task. Related to this overall task are the following sub-tasks:

- SWAT modifies plants that have ozone in some months and not in others. Some plants have this quality because they had ozone installed during the ICR data collection period. To better represent the actual initial technology level in such plants, SWAT installs a raw water ozone system in the plant-months without ozone initially. SWAT sizes the ozone dose based on the average ozone to TOC ratio in the months with ozone.

- SWAT runs each initial plant-month and saves the following key for use in later modification steps:
  - Finished water pH target
  - Finished water total chlorine residual target
  - Location and type of main primary disinfectant dose
  - Location of an additional chlorine dose (if any) contributing to CT credit
  - Location of any chlorine and/or ammonia doses for secondary disinfection (if one of these is not found, it is added prior to the plant effluent with a zero dose)
  - Location and magnitude of first coagulant dose
  - Precipitative softening status (yes or no)
  - Location and magnitude of first lime dose in softening plants
  - Location of last recarbonation dose in softening plants (and pH after this dose)

- SWAT calculates EC/ES compliance ratios for each initial plant month and the overall initial plant. The overall initial plant EC ratio is calculated as the

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average of all the initial plant-monthly EC/ES ratios. See Section 2.7.3 for further details regarding SWAT calculations of EC/ES compliance ratios.

- SWAT adds a reservoir (two-hour detention time, $T_{10}/T_{theoretical}$ ratio of 0.5) just prior to the effluent of any initial process train that does not have any unit processes with a volume. Such "process trains" (no process trains actually existed in these situations) typically occurred in unfiltered ICR systems. Without adding such a reservoir to provide contact time, it would be pointless for SWAT to process such a "plant" since the achievement of disinfection requirements would not be possible.

- SWAT adds a 1-mg/L chlorine dose at the beginning of any initial process train that does not have a disinfectant dose. This dose is added so that the "plant" has the possibility of achieving disinfection requirements.

- SWAT sets controlling disinfection requirements based on comparison of inputted criteria, predicted plant disinfection performance, disinfection benchmarking inputs, and calculated disinfection benchmarks (See Section 2.4.2 for a discussion of disinfection requirements and benchmarking calculations).

- SWAT determines the eligibility of the plant to switch to chloramines and to have its clearwell baffled based upon SWAT inputs (and a random number generator, as needed).

2.7.2 "Adjust Disinfection" Step

This step adjusts the primary disinfectant dose(s) in any initial plant-months predicted to not comply with disinfection requirements in an attempt to bring the plant into disinfection compliance. No modifications are made to attempt to bring the plant into compliance with DBP requirements. That is, SWAT does not lower disinfectant doses in this step in an attempt to meet DBP requirements along with disinfection requirements. Thus, the only actions this step performs on plant-months not complying with disinfection requirements are:

- Adjust the primary disinfectant dose(s) to achieve disinfection compliance

- Re-set the secondary disinfection dose(s) to achieve target effluent Cl_2 residual

2.7.3 "EC/ES" Step

This step modifies coagulant and/or lime doses in process trains from the "Adjust Disinfection" step if the overall plant EC/ES compliance ratio is less than 1.0. In SWAT, the overall plant compliance ratio is calculated as the average of the EC/ES compliance ratios for all the "VALID" plant-months that SWAT runs for that overall plant. Figure 2-14 indicates how SWAT determines these monthly EC/ES compliance ratios.

In the case where a plant is not meeting EC/ES requirements (overall plant compliance ratio less than 1.0), SWAT modifies the coagulant and/or lime doses in the plant-months comprising that plant using the following guidelines:

- Doses are only modified in plant-months with an EC compliance ratio less than 1.0.

- Doses are never decreased.

- For conventional coagulation plants, the first alum or ferric dose in the process train is adjusted to satisfy at least one of the following conditions:
  - TOC removal ratio (equal to percent TOC removal achieved divided by percent TOC removal required) between 0.95 and 1.05 is attained
  - finished water TOC alternative compliance criterion is met (+/- 5%)
  - maximum allowed dose is needed (based on a maximum equivalent alum to total organic carbon (TOC) ratio of 10.0)

- For softening plants, both the first alum or ferric and lime doses are adjusted upward to satisfy at least one of the following conditions:
  - TOC removal ratio (equal to percent TOC removal achieved divided by percent TOC removal required) between 0.95 and 1.05 is attained
  - finished water TOC alternative compliance criterion is met (+/- 5%)
  - finished water alkalinity falls below 60 mg/L as $CaCO_3$
  - magnesium hardness removal exceeds 10 mg/L as $CaCO_3$
  - the maximum allowed lime dose (300 mg/L) is needed

After any coagulant and/or lime doses are adjusted, primary and secondary disinfectant doses are re-calculated to meet inactivation and residual disinfectant targets.

2.7.4 "Turbo Coagulation" Step

As Section 2.3 notes, this step represents an advanced level of coagulation that targets a level of TOC removal that approximately 25% of ICR plants were observed to achieve during the ICR data collection effort. "Turbo Coagulation" is an optional SWAT decision tree step, which, if selected, is implemented similarly to the "EC/ES" step, except:

- SWAT uses EC/ES-modified process trains as the starting points for the modifications in this step.

- The TOC removal matrix is a 4x3, not a 3x3 matrix (there is a set of requirements for plants with raw water TOC < 2.0 mg/L).

- There are no alternative compliance criteria (except for the maximum coagulant dose criterion noted below).

- Coagulant and/or lime doses are adjusted to achieve:
  - required TOC removal ratio (+/- 10%)
  - maximum allowable dose (same maximums as for EC/ES)

After any coagulant and/or lime doses are adjusted, primary and secondary disinfectant doses are re-calculated.

Calculate TOC Removal Ratio (TOCRR) = (% TOC removal achieved) ÷ (% TOC removal required)

Is TOCRR ≥ 1.0? —Yes→ $ECCR^1$ = TOCRR

No ↓

Is TOCRR $\geq 0.95?^2$ —Yes→ ECCR = 1.0

No ↓

Are any ACC^3 met? —Yes→ ECCR = 1.0

No ↓

Is max. coagulant dose used? —Yes→ ECCR = 1.0

No ↓

ECCR = TOCRR

Notes:
1) ECCR = enhanced coagulation compliance ratio
2) 0.95 is used here because SWAT uses an iterative routine to find coagulant doses that bring the TOCRR to within 5% of 1.0.
3) ACC = alternative compliance criteria. SWAT checks if a plant-month meets any one of 5 alternative compliance criteria:
   • Raw water TOC < criterion
   • Raw water (T)SUVA < criterion
   • Finished water TOC < criterion
   • Finished water alkalinity < 60 mg/L as $CaCO_3$ (for softening plants)
   • Magnesium removal ≥ 10 mg/l as $CaCO_3$

Figure 2-14: SWAT Determination of Monthly EC/ES Compliance Ratio

2.7.5 "Move Chlorine" Step

This decision tree step only applies to plants using free chlorine as the mode of primary disinfection in every "VALID" plant-month to be run. The goal of this step is to move the point of free chlorine disinfection to a post-coagulation location. When SWAT implements this step, EC/ES-modified process trains serve as the starting points, and the following modifications are made:

- All chlorine points contributing to CT are removed.

- A single chlorine point is added to the process train prior to the last filter if a filter exists.

- If no filter exists, the chlorine point is added after the last rapid mix.

- If no filter or rapid mix exists, the chlorine point is added to raw water.

- Secondary disinfectant doses are re-set.

- If disinfection or MRDL criteria are not met, and the plant is eligible for baffling modifications:
  - basins and/or clearwells downstream of the chlorine dose are modified in every plant-month so that $T_{10}/T_{theoretical}$ is set equal to $T_{50}/T_{theoretical}$ (with a maximum value of 0.80)
  - Primary and secondary disinfectant doses are re-set.

2.7.6 "Chlorine Dioxide" Step

The goal of this SWAT decision tree step is to implement post-filter chlorine dioxide addition for primary disinfection. This step applies to plants with an initial technology level less than or equal to chlorine dioxide, and EC/ES-modified process trains serve as starting points for the modification process. The following process train modifications are executed:

- All chlorine and/or chlorine dioxide doses contributing to CT are removed.

- A single chlorine dioxide point is added after the last filter, if a filter exists.

- If no filter exists, the chlorine dioxide is added after the last rapid mix.

- If no filter or rapid mix exists, the chlorine dioxide is added to raw water.

- Four chlorine dioxide contactors, each with T_{50} equal to approximately 30 minutes and $T_{10}/T_{th} = 0.5$, are added after the chlorine dioxide addition point. The purpose of this is to assure that the WTP Model can adequately characterize the chlorine dioxide residual profile for CT calculation. The assumption of installation of a contacting system is not made in anticipation that utilities would install new contactors; it is more an assumption that

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utilities would find a way to characterize chlorine dioxide residual decay in existing clearwells. The additional contactors do not affect any other WTP model predictions.

- If a chlorite MCL is active for a given SWAT run, the chlorine dioxide dose is set equal to the chlorite MCL divided by 0.71. This is approximately the maximum dose that can be applied given the WTP Model algorithm for chlorite formation, which predicts chlorite as 0.70 times the chlorine dioxide dose.

- If no chlorite MCL is active, the chlorine dioxide dose is set similarly to other primary disinfectant doses to achieve a CT ratio of 1.0 to 1.2 for the limiting pathogen.

- Once the chlorine dioxide dose has been established, the secondary disinfectant doses are re-set.

2.7.7 "UV Disinfection" Step

Process improvement with UV disinfection is an optional SWAT decision tree step. When included in the decision tree, this step applies to all plants, and EC/ES-modified process trains serve as starting points. In the "UV Disinfection" step, SWAT does not move, add, or remove any treatment units. Furthermore, the only effect of the UV disinfection process that SWAT considers is the user-entered log inactivation credit for *Giardia*, viruses, and *Cryptosporidium*. Thus, SWAT executes the following procedures during this step:

- The log inactivation required (by free chlorine, chloramines, ozone, or chlorine dioxide) for each pathogen is decreased by the (user-entered) credit provided by UV disinfection.

- The main primary disinfectant dose (such as chlorine, ozone, or chlorine dioxide) is modified to achieve the target CT ratio.

- Any additional chlorine point that contributes to CT is modified downward, if necessary.

- Secondary disinfectant doses are re-set.

2.7.8 "Raw Water Ozone" Step

The "Raw Water Ozone" decision tree step applies to all plants with an initial technology level less than or equal to "MF/UF" (based on the SWAT decision tree order). This step is optional for small systems, and EC/ES-modified process trains serve as starting points. SWAT implements the following changes to process trains during this step:

- All existing chlorine, chlorine dioxide, ozone, and ammonia doses along with any existing ozone contactors are removed.

- An ozone contacting system is added at the plant influent. The ozone contacting system consists of:
  - Single ozone dose
  - Single application chamber (T_{50} = 2 minutes at design flow; T_{10}/T_{th} = 0.1)
  - Four dissipation chambers (each with T_{50} = 2.5 minutes at design flow; T_{10}/T_{th} = 0.7)

- The ozone dose is set to achieve the target CT ratio for the limiting pathogen.

- If the SWAT "Biofiltration On?" checkbox is checked (See Section 2.4.1), coagulant doses are re-set to achieve EC/ES compliance with TOC removal across the biofilter taken into consideration.

- A contactor (T_{50} = approximately 5 minutes), preceded by the chlorine dose used to achieve secondary disinfection goals, is added downstream of the last filter in the process train to provide a short free chlorine contact time. Such a free chlorine contact time would likely be used in the design of an ozone plant to inactivate any bacteria sloughing off of a biological filter. Note that unless *Cryptosporidium* inactivation is required for the process train, the limiting (smallest) CT ratio likely will be greater than the 1.0 to 1.2 range targeted during the sizing of the ozone dose due to the CT contribution of the 5-minute free chlorine contactor.

- If chloramines are to be used as the secondary disinfectant, ammonia is added immediately downstream of the 5-minute contactor.

- Both the chlorine and ammonia doses are sized to achieve the target residual at the plant effluent.

2.7.9   *"Settled Water Ozone" Step*

The goal of this process improvement step is to implement ozone for advanced disinfection, but reduce the required ozone dose to control bromate formation. Since the pH following coagulation is typically less than the raw water pH due to the addition of acidic coagulants, additional bromate control is achieved. This step applies to the same plants to which the "Raw Water Ozone" step applies, and raw water ozone-modified process trains are the starting points. SWAT executes the following procedures to implement this step:

- The raw water ozone contacting system is removed.

- If a filter exists in the process train, an ozone contacting system is added just upstream of the last filter.

- If no filter exists in the process train, an ozone contacting system is added to raw water.

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- The chlorine dose inserted just after the last filter during the "Raw Water Ozone" step is set to zero so as not to interfere with the determination of the settled water ozone dose.

- If the SWAT "Biofiltration On?" checkbox is checked (See Section 2.4.1), coagulant doses are re-set to achieve EC/ES compliance with TOC removal across the biofilter taken into consideration.

- If it is a lime-softening process train,
  - all existing carbon dioxide doses downstream of the last filter are removed
  - a new carbon dioxide dose is added prior to the ozone contacting system
  - the new carbon dioxide dose is sized to bring the pH of ozonation down to 8.5 (a maximum carbon dioxide dose of 50 ppm is allowed)
    - if the carbon dioxide could not meet the goal of pH equal to 8.5, an additional sulfuric acid dose is added upstream of the ozone contacting system and sized to bring the pH of ozonation down to 8.5 (a maximum sulfuric acid dose of 50 ppm is allowed)

- The settled water ozone dose is set to achieve the target CT ratio for the limiting pathogen.

- The secondary disinfectant doses (which are still set-up in the same configuration as in the "Raw Water Ozone" step) are re-set to achieve the target chlorine or chloramine residual.

2.7.10 *"MF/UF" Step*

The MF/UF decision tree step applies to all plants with an initial technology level less than that associated with the "MF+NF50" decision tree step. EC/ES-modified process trains are the starting points for the "MF/UF" step. In SWAT, the primary benefit that MF/UF implementation provides to a process train is the user-defined log-removal credit associated with the membranes. This permits primary disinfectant doses to be decreased, lowering DBP formation. SWAT executes the following procedures to implement MF/UF in process trains:

- All chlorine and ammonia doses contributing to CT are removed.

- Any existing MF/UF processes are removed.

- A new MF/UF process is inserted after the last filter, if there is an existing filter in the process train.
  - If there is no filter, the new MF/UF process is inserted in raw water.

- 100% recovery is assumed for the MF/UF process.

- The log inactivation required is recalculated, taking into consideration MF/UF log removal credits.

- If ozone or chlorine dioxide is the main primary disinfectant, its dose is re-set to achieve the target CT ratio.

- If chlorine was the primary disinfectant and log inactivation of *Cryptosporidium* is required beyond the log removal credit, this plant-month will not be able to meet disinfection requirements. If it is a "SMART" run, SWAT discontinues process modifications at this point. If it is a "MONSTER" run, SWAT continues as described below and will end up inserting chlorine addition point with the maximum dose allowed.

- If chlorine was the primary disinfectant and log inactivation of *Cryptosporidium* is not required, but inactivation of *Giardia* or viruses is required, SWAT executes the following steps:
  - a chlorine dose is added after the MF/UF process, unless GAC occurs in the process train downstream of MF/UF
    - if GAC occurs after MF/UF, the chlorine is added after GAC
  - the chlorine dose is sized in an attempt to meet the target CT ratio for the limiting pathogen
  - if disinfection or MRDL criteria are not met, and the plant is eligible for baffling,
    - basins and/or clearwells downstream of the chlorine dose are modified so that $T_{10}/T_{theoretical}$ is set equal to $T_{50}/T_{theoretical}$ (with a maximum value of 0.80)
    - the chlorine dose is re-set to achieve the target CT ratio of the limiting pathogen
    - the secondary disinfectant doses are re-set
  - if disinfection or MRDL criteria are still not met,
    - a contactor with a maximum T_{50} equal to 2 hours (and $T_{10}/T_{theoretical} = 0.5$) is installed after the chlorine dose
    - the chlorine dose is re-set to achieve the target CT ratio
    - the secondary disinfectant doses are re-set

Note that when SWAT implements baffling changes to existing basins or adds contactors to bring a certain plant-month into compliance, it makes these same capital improvements to all other plant-months. If more than one plant-month requires such modifications to meet disinfection and MRDL requirements, the changes associated with the plant-month requiring the most intensive improvements are implemented in all other plant-months.

2.7.11 "GAC10" Step

The SWAT "GAC10" decision tree step applies to all plants with initial technology level less than "GAC20" (per decision tree order) with multiple exceptions. This step does not apply to:

- Plants that have ozone or chlorine dioxide. Those plants would skip directly to the "GAC10 + Raw Water Ozone" or "GAC10 + Chlorine Dioxide" decision tree steps.

- Softening plants

- Small systems

In SWAT, a GAC10 system is assumed to have the following characteristics:

- The system has enough parallel contactors operating with staggered TOC effluent concentrations that a steady blended effluent TOC concentration is maintained as contactors are taken off-line for reactivation.

- Contactors are brought on-line and taken off-line as flow changes to maintain an operating empty bed contact time (EBCT) of 10 minutes.

- The reactivation interval is between 90 and 360 days (SWAT estimates the optimal reactivation interval on a plant-by-plant basis in this process improvement step).

Because installation of a GAC process constitutes achievement of enhanced coagulation requirements, process trains from the "Initial Plant" step (as opposed to the "EC/ES" step) are the starting points for implementation of the "GAC10" step. SWAT executes the "GAC10" step as follows:

- All chlorine and ammonia doses contributing to CT are removed.

- Any existing GAC unit processes are removed.

- SWAT sets the reactivation interval at 360 days for the GAC10 system to be added.

- A GAC10 system is added after any existing MF/UF process, if it exists.
    - If no MF/UF unit exists, the GAC10 system is added after the last filter, if one exists.
    - If no MF/UF unit or filter exists, the GAC10 system is added to raw water.

- A chlorine point is added after the GAC10 system.

- The chlorine dose is set to achieve the target CT ratio for the limiting pathogen.

- Secondary disinfectant doses are set to achieve the target chlorine residual.

- If disinfection or MRDL criteria are not met and the plant is eligible for baffling,
    - basins and/or clearwells downstream of the chlorine dose are modified so that $T_{10}/T_{theoretical}$ is set equal to $T_{50}/T_{theoretical}$ (with a maximum value of 0.80)
    - the chlorine dose is re-set to achieve the target CT ratio for the limiting pathogen
    - the secondary disinfectant doses are re-set

- If SWAT is being run in "MONSTER" mode, this step ends at this point, yielding output associated with a GAC reactivation interval of 360 days.

- If SWAT is being run in "SMART" mode, and if disinfection, MRDL, or DBP compliance criteria are not met using a GAC reactivation interval of 360 days, the "GAC10" step modifications are repeated using a smaller reactivation interval. This iterative process continues until full compliance is reached or the smallest reactivation interval has been employed. SWAT employs the following reactivation intervals:
    - 360 days
    - 300 days
    - 240 days
    - 180 days
    - 120 days
    - 90 days

2.7.12 "GAC20" Step

The "GAC20" SWAT decision tree step applies to the same plants and is implemented in the same fashion as the "GAC10" step with the following exceptions:

- This step applies to plants with an existing GAC system of any size, not just plants with GAC systems characterized as less aggressive than GAC20.

- GAC20 systems are added to process trains instead of GAC10 systems.

- For SWAT, a GAC20 system is defined similarly to a GAC10 system, except that the operating EBCT is 20 minutes.

2.7.13 "GAC10 + Chlorine Dioxide" Step

The "GAC10 + Chlorine Dioxide" step applies to the same plants and is implemented in the same fashion as the "GAC10" step with the following exceptions:

- This step also applies to plants with chlorine dioxide in their initial process trains.

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- Any existing chlorine dioxide application points are removed.

- A chlorine dioxide point and chlorine dioxide contactors are added (in similar fashion to those in the "Chlorine Dioxide" step) immediately after the GAC10 unit process.

- The chlorine dioxide dose is sized in similar fashion to that in the "Chlorine Dioxide" step.

- No baffling of existing basins, contactors, and/or clearwells is performed.

2.7.14 "GAC10 + UV" Step

The "GAC10 + UV" step applies to plants with initial technology level less than or equal to "GAC10," except for initial plants with ozone (which would skip to the "GAC10 + Raw Water Ozone" step). This step also applies to plants with an initial technology level equal to "GAC10 + Chlorine Dioxide." Similar to any GAC technology, this step does not apply to lime-softening plants or small plants.

SWAT implements the "GAC10 + UV" step in similar fashion to the "GAC10" step with the following exceptions:

- Any existing chlorine dioxide doses are removed along with existing GAC processes and chlorine and ammonia doses contributing to CT credit.

- Inactivation to be achieved with the free chlorine dose that is installed downstream of the GAC10 system is reduced by the amount of inactivation credit established for the UV unit in the "UV Disinfection" inputs tab (see Section 2.4.3).

2.7.15 "GAC10 + Raw Water Ozone" Step

The "GAC10 + Raw Water Ozone" step applies to all plants with initial technology level less than or equal to "GAC10 + Raw Water Ozone," except for:

- Plants with existing GAC units with EBCT > 10 minutes (such plants are classified as having a technology level equal to or greater than "GAC20" and skip directly to the "GAC20 + Raw Water Ozone" step)

- Softening plants

- Small systems

This step is implemented in similar fashion to the GAC10 step, except:

- Any existing ozone doses, ozone contactors, or chlorine dioxide doses are removed.

- An ozone contacting system (the same as that added in the "Raw Water Ozone" step) is added to raw water.

- The ozone dose is sized to achieve the target CT ratio for the limiting pathogen.

- Secondary disinfectant doses are configured in similar fashion to those in the "Raw Water Ozone" step (*i.e.* with a 5-minute contactor downstream of the chlorine doses used for secondary disinfection), except that the chlorine dose is installed following GAC instead of the last filter.

2.7.16 *"GAC10 + Settled Water Ozone" Step*

This decision tree step applies to exactly the same plants as the "GAC10 + Raw Water Ozone" step, and the "GAC10 + Raw Water Ozone" process trains serve as the starting points for this modification step. To implement this decision tree step, SWAT executes the following:

- SWAT removes the raw water ozone system installed in the "GAC10 + Raw Water Ozone" step.

- SWAT installs an ozone system upstream of the last filter in the process train unless no filter exists.
  - If no filter exists, SWAT installs the ozone system in raw water.

- SWAT sets any chlorine doses to zero and sizes the ozone dose to meet the target CT ratio for the limiting pathogen.

- SWAT re-sets the secondary disinfection dosages.

2.7.17 *"GAC20 + Chlorine Dioxide" Step*

The "GAC20 + Chlorine Dioxide" step applies to all plants with initial technology level less than or equal to the "GAC20 + Chlorine Dioxide," except for:

- Plants with ozone in initial process trains (such plants would skip directly to the "GAC20 + Raw Water Ozone" decision tree step)

- Softening plants

- Small systems

This step is implemented in the same manner as the "GAC10 + Chlorine Dioxide" step, except a GAC20 system is added instead of a GAC10 system.

2.7.18 "GAC20 + UV" Step

The "GAC20 + UV" step applies to all plants with initial technology level less than or equal to "GAC20 + UV," except for:

- Plants with ozone in initial process trains (such plants would skip directly to the "GAC20 + Raw Water Ozone" decision tree step)

- Softening plants

- Small systems

This step is implemented in the same manner as the "GAC10 + UV" step, except a GAC20 system is added instead of a GAC10 system.

2.7.19 "GAC20 + Raw Water Ozone" Step

The "GAC20 + Raw Water Ozone" step applies to all plants with initial technology level less than or equal to "GAC20 + Raw Water Ozone," except for:

- Softening plants

- Small systems

This step is implemented in the same manner as the "GAC10 + Raw Water Ozone" step, except a GAC20 system is added instead of a GAC10 system.

2.7.20 "GAC20 + Settled Water Ozone"

This step applies in all the same instances as the "GAC20 + Raw Water Ozone" step, and "GAC20 + Raw Water Ozone" process trains serve as the starting points for modifications. This step is implemented similarly to the "GAC10 + Settled Water Ozone" step except that GAC20 is used instead of GAC10.

2.7.21 "MF + NF50" Step

The SWAT "MF + NF50" decision tree step represents a "greenfield" integrated membrane plant consisting of the following unit processes (listed in order):

- MF/UF
    - with the user-defined log removal credits for *Giardia*, viruses, and *Cryptosporidium,* and an assumed recovery of 100%

- Nanofiltration (NF) with 50% of the MF/UF stream treated and 50% bypassed
    - With the user-defined molecular weight cut-off and recovery, and TOC, UV254, and bromide removals (no log removal credit due to bypass)

- Chlorine addition point (for log inactivation, if required)

- Existing clearwell
    - existing clearwells are the only features of an "Initial Plant" process train that are retained in this step

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- baffling improvements are made ($T_{10}/T_{theoretical}$ is set equal to $T_{50}/T_{theoretical}$ with a maximum value of 0.80) if the plant is eligible, and the improvements are needed to meet disinfection and MRDL requirements

- Additional chlorine contact basin with T_{50} up to 2 hours (if needed)

- Secondary disinfectant dosages

This decision tree step applies to all plants with the exception of lime-softening plants in which more than 50% of the flow would require NF treatment in any given plant-month to achieve a finished water total hardness concentration that is less than or equal to that in the initial plant-month.

2.7.22 "MF + NF75" Step
This step is similar to "MF + NF50," except the NF process treats 75% of the MF/UF effluent flow. Furthermore, the step applies to all plants with the exception of lime-softening plants in which more than 75% of the flow would require NF treatment in any given plant-month to achieve a finished water total hardness concentration equal to that in the initial plant-month.

2.7.23 "MF + NF100" Step
This step is similar to "MF + NF50" and "MF + NF75," except the NF process treats 100% of the MF/UF effluent flow. Also, since the entire stream is treated by NF, log removal credit for the NF process is taken into account. Furthermore, this step applies to plants with any initial configuration, and SWAT does not require that the softening achieved by full-stream NF treatment by as good as that achieved by precipitation in lime-softening plants.

2.7.24 " With Chloramines" Steps
Each of the steps described in Sections 2.7.3 ("EC/ES") through 2.7.23 ("MF+NF100") has an associated "with Chloramines" step directly following it in the SWAT decision tree. SWAT implements these steps in the same fashion as the steps that precede them, but with the additional potential operation of changing the secondary disinfectant to chloramines.
These "with Chloramines" steps are the only decision tree steps (aside from the first two in the tree) that apply to plants using chloramines in the distribution system under their initial configuration. For SWAT, plants defined as "using chloramines initially" are plants that use chloramines in the DS in greater than or equal to 50% of their months (see related discussions in Sections 2.4.1 and 2.5.1).
The "with Chloramines" steps apply to some or all plants using free chlorine in the distribution system initially. The user inputs define how the eligibility to go to chloramines should be determined for plants using free chlorine initially (see Section 2.4.1).
Table 2-2 below shows how SWAT implements chloramines in the DS for different inputs settings for plants to which "with Chloramines" steps apply.

When SWAT implements chloramines in a plant-month that originally had free chlorine in the DS, a target total chlorine residual of 2.0 mg/L is used.

Table 2-3: Implementation of Chloramines in the Distribution System for a Plant		
Typical DS Disinfectant in Initial Plant	Did User Select the "All Months Go To Chloramines" Option	
	Yes	No
Chloramines	SWAT implements chloramines in DS in any month using free chlorine in DS	SWAT does not change the DS disinfectant in any month
Free Chlorine	SWAT implements chloramines in DS in all months using free chlorine in DS	SWAT implements chloramines in DS in all months using free chlorine except for the warmest month

2.7.25 *Non-compliance*

During a "SMART" SWAT run, if a plant does not comply with disinfection and DBP requirements after the last step in the tree ("MF + NF100 with Chloramines"), an ending technology code of "99" is outputted to the AUX8 database for that plant. If the "SMART" run involves the outputting of process train and/or water quality data, SWAT will output this information for the last step that applied to that plant (either "MF + NF100" or "MF + NF100 with Chloramines") that was implemented for this non-complying plant.

2.8 SWAT Outputs

As shown in Figure 2-1, SWAT sends outputs to the AUX8 database. Furthermore, as discussed in Section 2.2, the SWAT run modes primarily differ by the type of output generated. This section provides further descriptions of SWAT outputs.

2.8.1 *Outputs Common to All SWAT Runs*

This section describes the SWAT outputs that are common to all SWAT run modes.

- Run description: SWAT stores a run identification number, the user-entered description of that run (created through the SWAT GUI), the date and time of the run, and the initials of the user in the AUX8 database table entitled "TUXRUN." The first field (column) in the "TUXRUN" table contains the run identification number. This number serves as a reference to other AUX8 tables containing SWAT outputs so that the user can discern which outputs belong to which SWAT run.

- Run inputs: SWAT stores the inputs entered by the user through the SWAT GUI for a given run in the AUX8 table called "TUXPARAM." In this table there are fields to hold the run identification number, the input parameter code, and the input parameter value. "TUXPARAM_D" contains a key that defines the input parameter codes.

2.8.2 "SMART" SWAT Output

　　SWAT has three types of "SMART" run modes from which the user can choose on the "General" inputs tab. The following describes the outputs generated by these different modes.

- "SMART (with Process Train & WQ Data)": This type of run generates the most detailed output of any "SMART" run type. The following points identify the specific outputs and where they can be found in the AUX8 database:
  - *Technology level at compliance*: SWAT stores a numerical code in the AUX8 database that corresponds to the technology level in the decision tree at which each "VALID" plant complied with the user-inputted disinfection and DBP criteria. This code is contained in "ENDTECH" field of the "TUXPLTRUN" table in AUX8. This field represents the last column in the "TUXPLTRUN" table and is marked "Technology_required_for_Compliance." Table 2-3 maps the numerical codes to the decision tree technology levels. AUX8 also contains the information presented in Table 2-3 in the "TUXTECH_D" table.
  - *Modified process train at compliance*: In this type of "SMART" run, SWAT stores the description of the modified monthly process trains at the technology level of compliance for each "VALID" plant. The type of process train information saved as output is similar to that required as SWAT input information is stored in several different AUX8 tables (note that data applicable to SWAT input process trains are shown in these same tables with a run identification number of zero):
    - "TUXUPRUN" shows the sequence of unit processes in the modified process train (along with predicted water quality, as discussed below). The SWAT user can find definitions for the unit process abbreviations shown in this table in the "TUXUP_D" table.
    - "TUXUPDOSE" shows the values of chemical doses for the modified process train. This table also contains a field which shows the chlorite to chlorine dioxide conversion ratio assumed for any chlorine dioxide addition points (this will always show 0.70). A field is also included which defines whether or not a lime dose is intended for pH adjustment, "P" or for softening, "S." Table 2-4 shows the units that are assumed for chemical doses in AUX8.
    - "TUXUPVOL" contains information describing unit processes with a volume, such as rapid mix units, flocculation basins, sedimentation basins, filters, ozone contactors, and reservoirs. The table contains fields that store the unit process volume (in gallons), the flow through the process (in mgd), and the $T_{10}/T_{theoretical}$ and $T_{50}/T_{theoretical}$ ratios. The table also contains fields that describe whether or not chlorinated backwash is used for a filter, the type of filter media, and the log removal of *Cryptosporidium* for a filter (this last field is not used by SWAT and should be ignored by the user).
    - "TUXUPGAC" stores process information for GAC units. The table contains fields that store the empty bed contact time, or EBCT, (in

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minutes) and the reactivation interval (in days). The SWAT user should ignore the last two fields (the right-most fields) in this table.

- – "TUXUPMBR" stores process information related to MF/UF and NF unit processes. The table includes fields for:
  - X Molecular weight cut-off (Daltons) for NF units
  - X Recovery (%) for NF units and MF/UF units
  - X Fraction of flow treated (%) for NF units
  - X Giardia, virus, and Cryptosporidium log removal credit (logs) for NF and MF/UF units
- ▪ *Water quality at compliance*: In this type of "SMART" run, SWAT also stores water quality predictions for finished water ("FINISH") and for delivered water at the "DS_AVG" and "DS_MAX" locations. The AUX8 table "TUXUPRUN" contains these outputs.

Table 2-4: SWAT Decision Tree Technology Codes			
Tech. Code	Technology Name	Tech. Code	Technology Name
0	Initial Plant	23	GAC10+ClO_2 with Chloramines
1	Adjust Disinfection	24	GAC10+UV
2	EC/ES	25	GAC10+UV with Chloramines
3	EC/ES with Chloramines	26	GAC10+Raw O_3
4	Turbo Coagulation	27	GAC10+Raw O_3 with Chloramines
5	Turbo Coagulation with Chloramines	28	GAC10+Settled O_3
6	Move Chlorine Point	29	GAC10+Settled O_3 with Chloramines
7	Move Chlorine Point with Chloramines	30	GAC20+ClO_2
8	Chlorine Dioxide (ClO_2)	31	GAC20+ClO_2 with Chloramines
9	ClO_2 with Chloramines	32	GAC20+UV
10	UV Disinfection (UV)	33	GAC20+UV with Chloramines
11	UV with Chloramines	34	GAC20+Raw O_3
12	Raw Water Ozone (Raw O_3)	35	GAC20+Raw O_3 with Chloramines
13	Raw O_3 with Chloramines	36	GAC20+Settled O_3
14	Settled Water Ozone (Settled O_3)	37	GAC20+Settled O_3 with Chloramines
15	Settled O_3 with Chloramines	38	MF+NF50
16	MF/UF	39	MF+NF50 with Chloramines
17	MF/UF with Chloramines	40	MF+NF75
18	GAC10	41	MF+NF75 with Chloramines
19	GAC10 with Chloramines	42	MF+NF100
20	GAC20	43	MF+NF100 with Chloramines
21	GAC20 with Chloramines	99	Non-compliance
22	GAC10+ClO_2		

- • "SMART (with WQ Data)": This type of run generates the same output as the "SMART (with Process Train & WQ Data)" run, except that no modified process train data is outputted to AUX8.

- • "SMART (no Process Train or WQ Data)": For this type of run, SWAT only stores the technology level at the point of compliance for each plant. No process train or water quality data is saved.

- "MONSTER": As noted in Section 2.2.2, in this run mode, SWAT runs all plants through all decision tree levels (with the exception that plants initially characterized as using chloramines in the distribution system only go through "with Chloramine" steps). In doing this, SWAT modifies the monthly process trains of every plant, so that compliance with disinfection criteria is achieved. SWAT stores the modified process train information and the treated water quality information from a "MONSTER" run in one AUX8 table, "TUXMONSTER." TUXMONSTER contains a compilation of the fields that are found in the various tables used to store similar information in a "SMART" run. Of course, since DBP compliance is not evaluated in a "MONSTER" run, there is no complying technology level output.

Table 2-5: Chemical Dose Codes and Units		
Chemical Code	**Chemical Name**	**Units**
ALUM	Aluminum sulfate	mg/L as Al
CAOH	Lime	mg/L as $Ca(OH)_2$
CL2	Chlorine (gas)	mg/L as Cl2
CLO2	Chlorine dioxide	mg/L as ClO_2
CO2	Carbon dioxide	mg/L as CO_2
IRON	Ferric chloride	mg/L as Fe
NH3_N	Ammonia	mg/L as N
O3	Ozone	mg/L as O_3
PPM	Potassium permanganate	mg/L as $KMnO_4$
SO2	Sulfur dioxide	mg/L as SO_2
SOC	Soda ash	mg/L as Na_2CO_3
SOH	Sodium hydroxide	mg/L as NaOH
SOY	Sodium hypochlorite	mg/L as Cl_2
SUA	Sulfuric acid	mg/L as H_2SO_4