Dynamic Waste Water Modeling for Coal Burning Power Plants

Greg P. Behrens[1], Mike T. Damian[2], and Steven V. Kosler[1]

[1]AECOM Corporation, 9948 Amberglen Blvd, Austin, TX 78720, [2]AECOM Corporation, 277 West Nationwide Blvd, Columbus, OH 43215

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INTRODUCTION

The recent promulgation of revised Effluent Limitation Guidelines (ELG) for steam-electric power plants requires many utilities to address their current wastewater systems for compliance. The revisions will be put in place as current NPDES permits are renewed. Two of the major requirements found in the ELGs are the prohibition against discharging any ash transport water (fly ash/bottom ash/economizer ash sluice water) and stringent treatment requirements for flue gas desulfurization system liquid discharges. At many stations multiple units send wastewater flows to combined processing systems. Understanding the effects of rerouting or eliminating specific streams is not always intuitive. AECOM has developed sophisticated models that mimic current modes of operation and can be used to simulate modified operations. A water/mass balance model of a station's existing and proposed wastewater management systems was developed using the multi-purpose probabilistic modeling platform GoldSim™, developed by GoldSim Technology Group, LLC, and the geochemistry model PHREEQC developed by U.S. Geological Survey (USGS, 2013).

MODEL DEVELOPMENT

The primary modeling objective was to produce a flexible run-time model that will predict the performance (i.e., wastewater effluent discharge quality) of the existing wastewater management systems and/or proposed or modified wastewater management systems under various wastewater input scenarios. The results of the model will also be used to identify needs for modifications to existing wastewater management systems or additional wastewater management systems to meet regulatory wastewater effluent limits.

The model uses GoldSim and PHREEQC software with the appropriate dynamic-link library (DLL) files that allow PHREEQC and GoldSim to be coupled and calculations to be performed for predictive modeling. The coupled GoldSim-PHREEQC model includes a constituent mass balance and simulates equilibrium chemical reactions (such as dissolution, precipitation, and sorption) and concentration changes within the water balance.

Model Advantages

The dynamic model is superior to simpler spreadsheet-based calculations because it can predict aqueous geochemical reactions and interactions between waste streams that may result in chemical precipitation. Precipitates that form drop to the bottom of waste water ponds, improving water quality in the remaining water. This can be significant in planning and budgeting for proposed power plant compliance modifications. These modeling procedures was originally developed to model acid mine drainage conditions associated with hard rock and coal mining, and have been adapted to model power plants.

Model development activities include the following:

- Review of existing power plant water balance and related information.
- Site visit to observe and document existing conditions, interview Owner's staff and search for archival information.
- Defining model input parameters, including but not limited to precipitation, evaporation, chemical constituents, wastewater management pond characteristics, wastewater management pond and plant operation scenarios/conditions, flows, etc.
- Quantifying uncertainties in key model input parameters to determine the appropriate method to model those parameters.
- Developing schematic drawings to ensure that all modeling components were incorporated into the model and future operations (if applicable) were identified and could be implemented in the model.
- Coding of the schematics into GoldSim.
- Developing the PHREEQC chemical reaction model.
- Developing a module to dynamically link the PHREEQC model to the GoldSim model.
- Developing the preliminary and final GoldSim file and model dashboards formats.
- Calibrating the chemical reaction (PHREEQC) model and GoldSim model against actual plant operating and wastewater management systems' operating data.

Total Suspended Solids and Reasonable Potential to Exceed

The development of a total suspended solids (TSS) predictive methodology was added to the GoldSim portion of the model. Water quality assessment calculations for Reasonable Potential to Exceed (RPE) analysis are also included.

The model has three major input data sources – the flow rates for the wastewater streams of interest, the analytical results for samples of those streams, and a relationship table that is used to pick a specific analysis for a given flow rate (or time increment). The range of concentrations predicted by the model can be compared to current or future discharge limits to assess the need for treatment. Changing inputs to the model can be easily done allowing examination of a wide range of possible options. The model input template was constructed with extra data entry ranges, permitting modeling of additional streams with minimal effort. Currently up to forty streams can be added, with sixty compositions per stream.

TYPICAL PLANT WASTE WATER SCHEMATIC

Figure 1 is a simplified diagram of a power plant waste water balance. A lake is the source of once through cooling water and service water for the plant. Sluice streams and other low volume wastes and runoff pass through a primary and secondary settling pond before reentering the lake. All of the streams shown would typically be sampled 3-4 times and analyzed for constituents of interest.

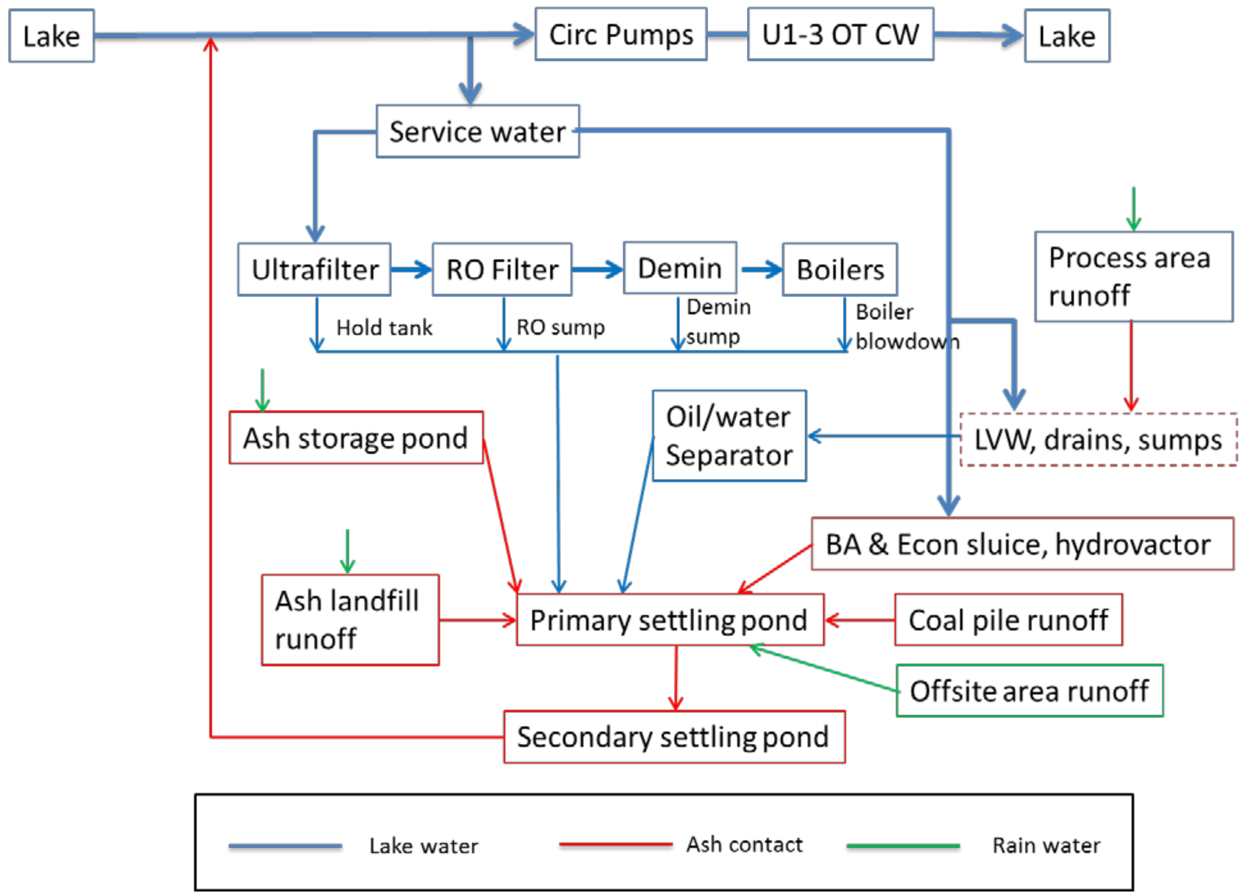

Figure 1. Simplified Waste Water Balance

MODEL SETUP

The GoldSim developer program allows runtime versions of applications to be customized for client-specific applications. For these projects a “player” version of the model is prepared and used to evaluate options. Figure 2 is an example of the home page for the model. The buttons link to input, output, and calculation setup pages. Note the ability to select which pond or treatment system is being modeled (fly ash/bottom ash pond). Sizing information is customized for each pond.

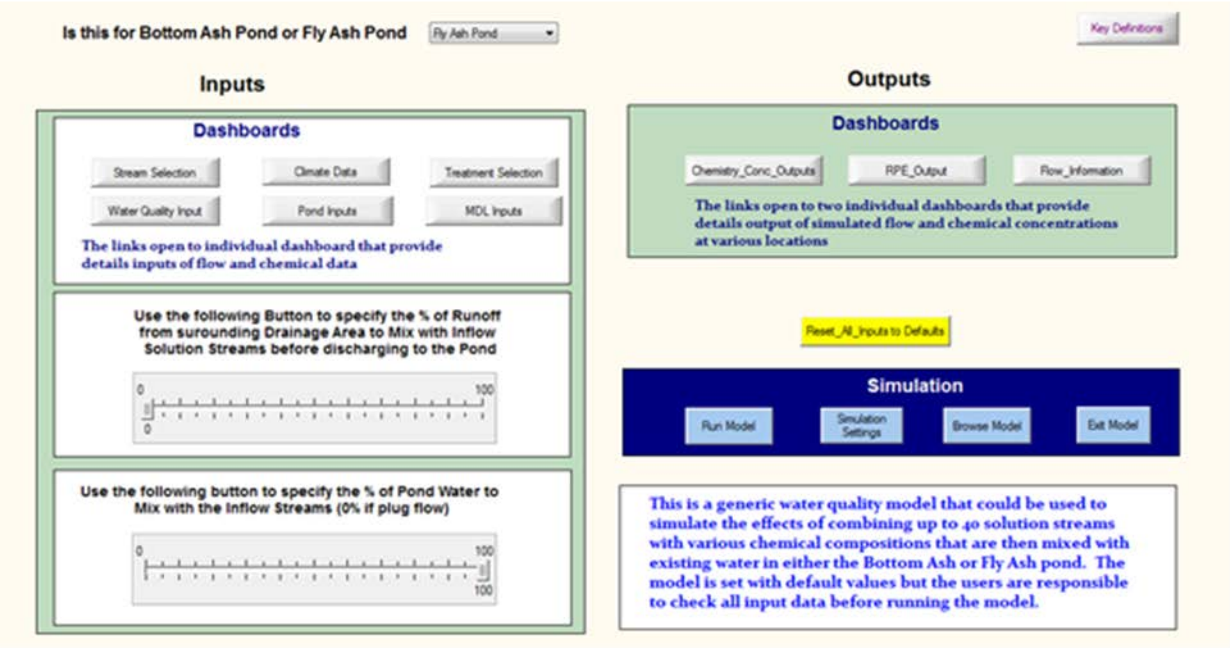

Figure 2 GoldSim Model Home Page

Within the model, relationships are defined in containers, as shown in Figure 3.

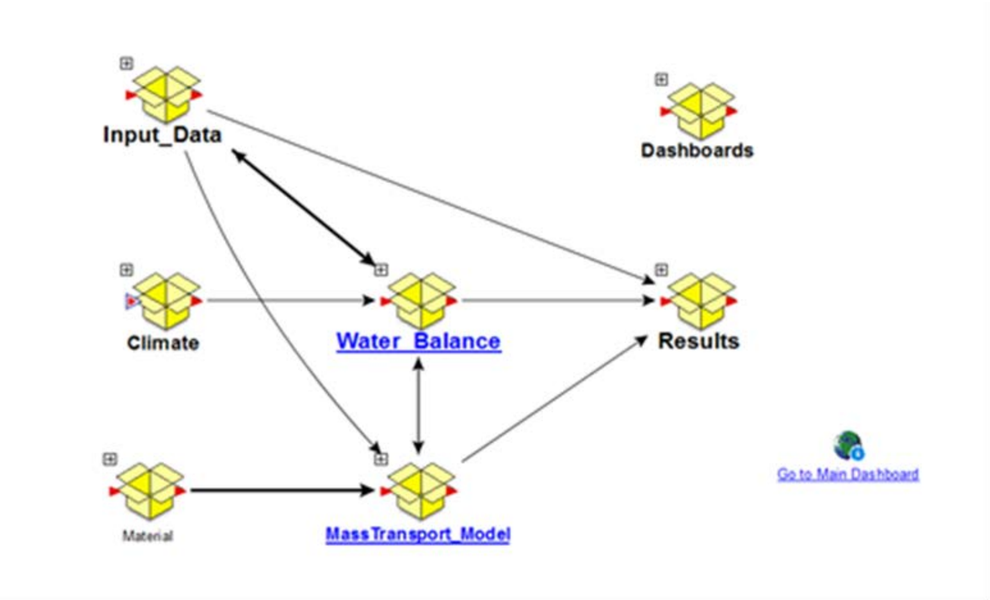

Figure 3 Model Container Structure

With the various containers, input data is stored and calculations are performed. Figure 4 shows input information. Figure 5 shows how the mass balance calculations of the blended stream is used as input to PHREEQC for equilibrium calculations, and then the results are returned for the next iteration

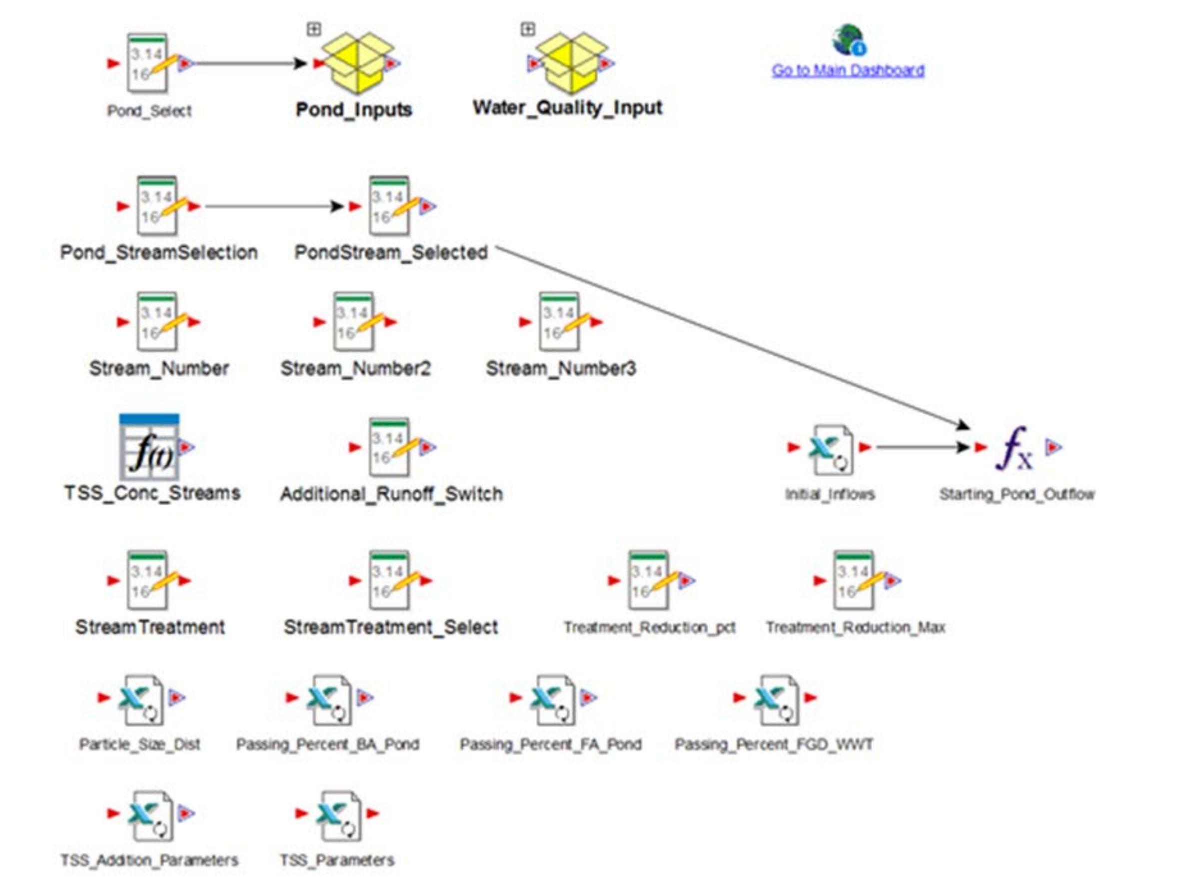

Figure 4 Input Container Information

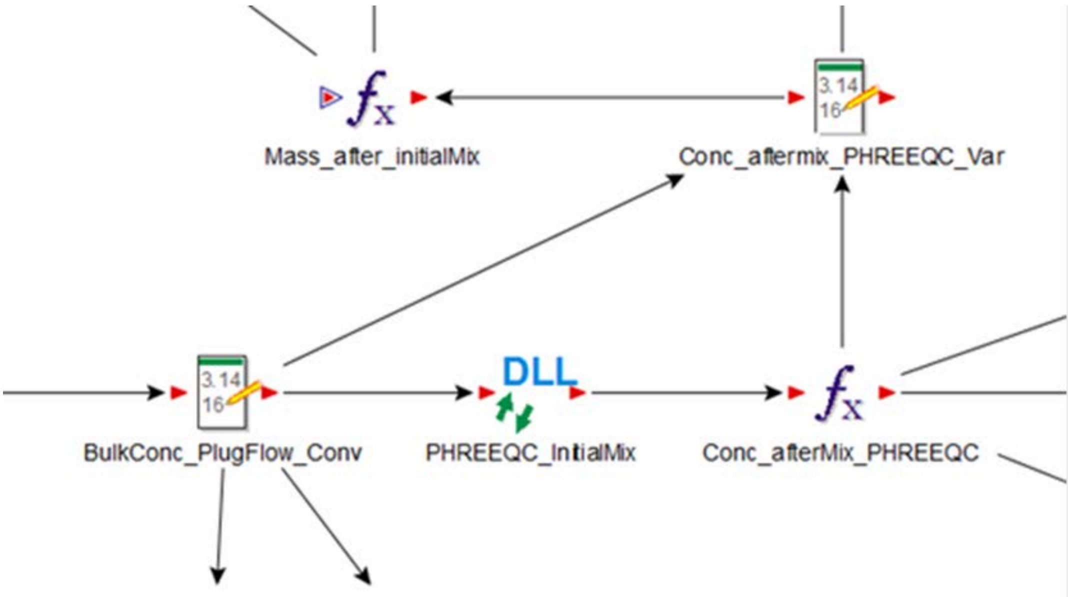

Figure 5 DLL Linkage Between GoldSim and PHREEQC

Batch files in PHREEQC can be modified to tune the model results to match measured data, which improves predictive accuracy going forward. This can be done by simulating the precipitation of gypsum and a partially crystalline form of aluminum hydroxide ($Al(OH)_3$) mineral in the bottom ash pond, and precipitation of gypsum and partially crystalline forms of aluminum and iron hydroxide ($Fe(OH)_3$) minerals, and surface complexation on hydrous ferric oxide (HFO) in the fly ash pond. On one project, some effluent constituents, including aluminum, arsenic, iron, lead, selenium, and zinc, were initially over-predicted by the model, but the adjustments described above produced good agreement with the measured data. Subsequent chemical monitoring data under real world operating conditions closely matched the results predicted by the model. In a second case, one unit of a two unit power plant was shut off for an extended time period. Monitoring data at outfall(s) showed substance concentration excursions, prompting the Owner to run the model. Model results predicted that an extended outage of one of the generating units could cause noncompliant discharges.

Figure 6 is the result dashboard which is used to show the results in either graphical or tabular form. The various rows of buttons present the calculations at initial blending, with pond blending, and at the outlet, for both dissolved and total concentrations. All of the results can easily be copied into spreadsheets for further analysis.

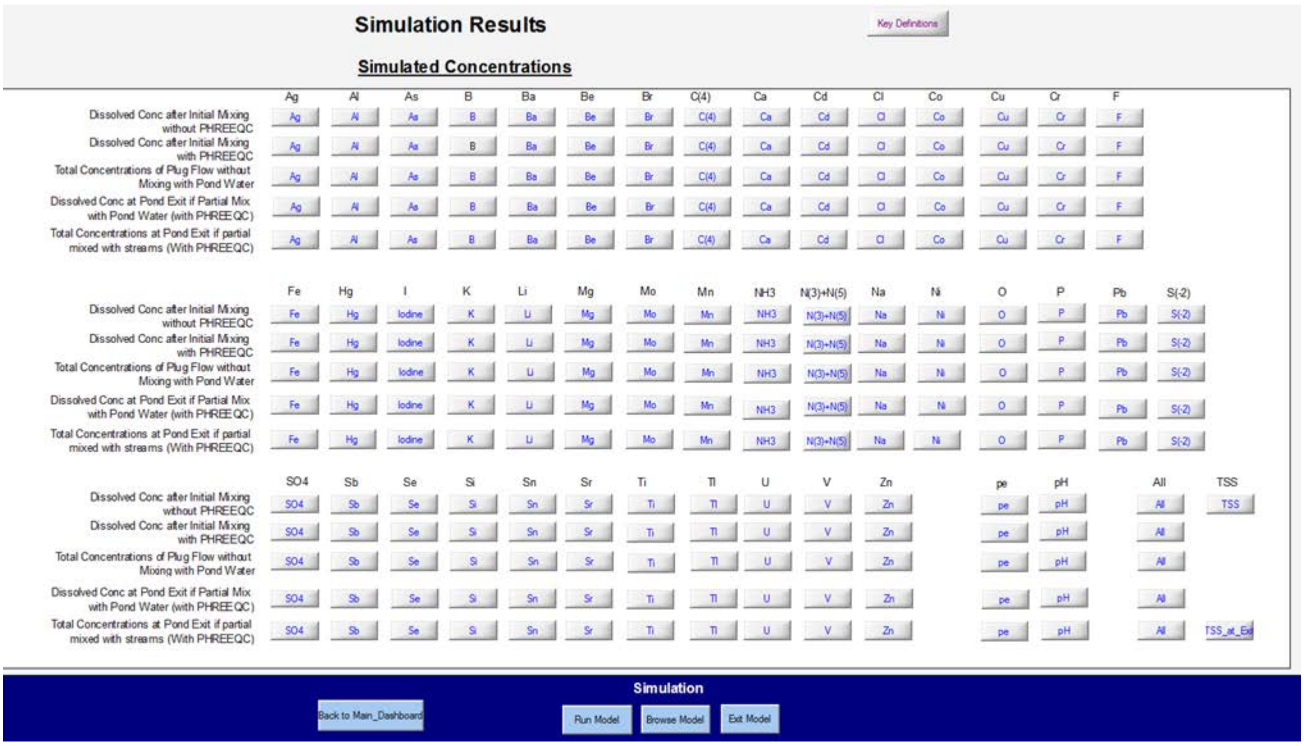

Figure 6 Results Dashboard

TYPICAL RESULTS

For the example waste water schematic in Figure 1, Figures 7 and 8 show the flow rates into the settling pond for the major streams over the time period analyzed. Lake water is used by a hydrovactor system to pneumatically convey fly ash, and is the major flow. Bottom ash and economizer ash sluice streams flow twice a day when a unit is in sluice mode service for about an hour. The effect of unit outages on the total pond flow is easily seen. Other low volume streams have minimal flow, except during rain event when their total flow increases from under 1 mgd to over 25. These spikes are seen in the model results for substances associated with the rain-derived streams (coal pile runoff, landfill runoff, etc.).

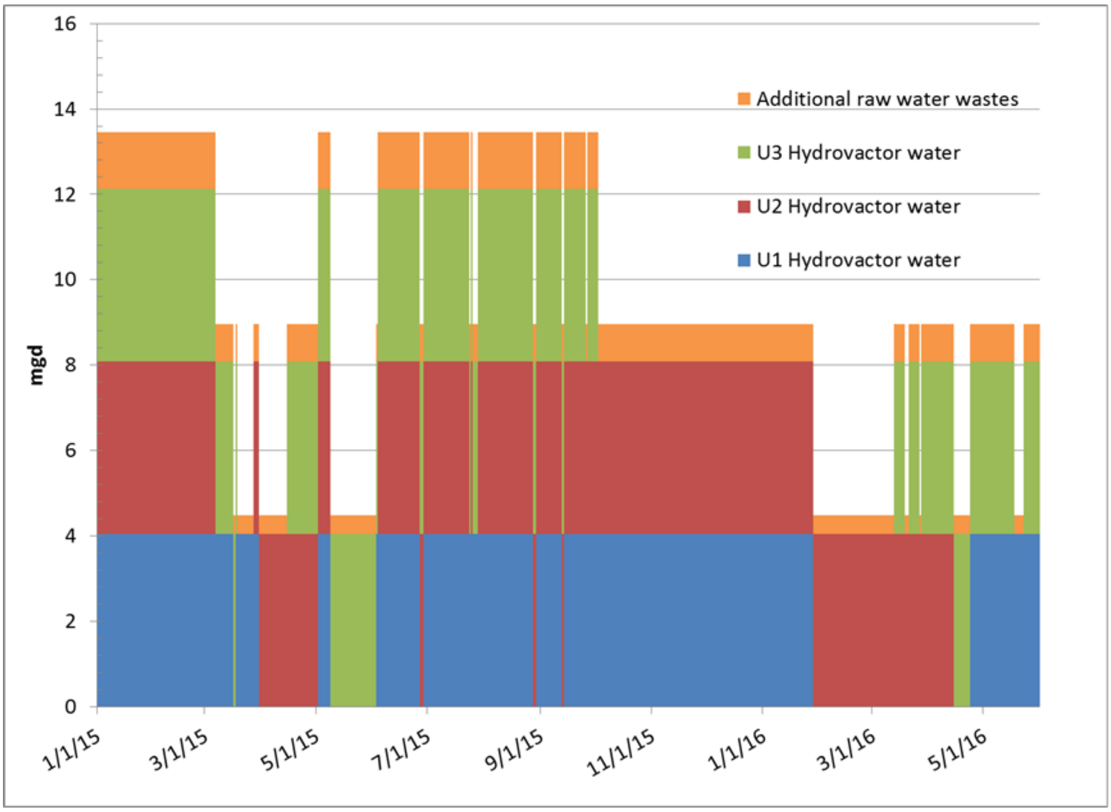

Figure 7 Major Flow Streams

Figure 8 Ash Sluice Streams

Figures 9, 10 and 11 plot selected major and trace substance concentrations over the time period using the model. Over 20 different streams enter the settling pond in varying amounts and concentrations over the period and were used to calculate the outlet concentration. Spikes can be examined for specific causes in the input data. These 500 simulation results were compared to the four actual measurements (of the example project) of the pond outlet from the sampling portion of the program. Coal pile runoff is the source of sulfate and selenium spikes seen in the first two figures. The sampling events in which pond effluent and all of the influent samples were obtained were not collected during high rain periods, so these predicted concentrations were never validated. Only a composite sampler would be able to show these effects.

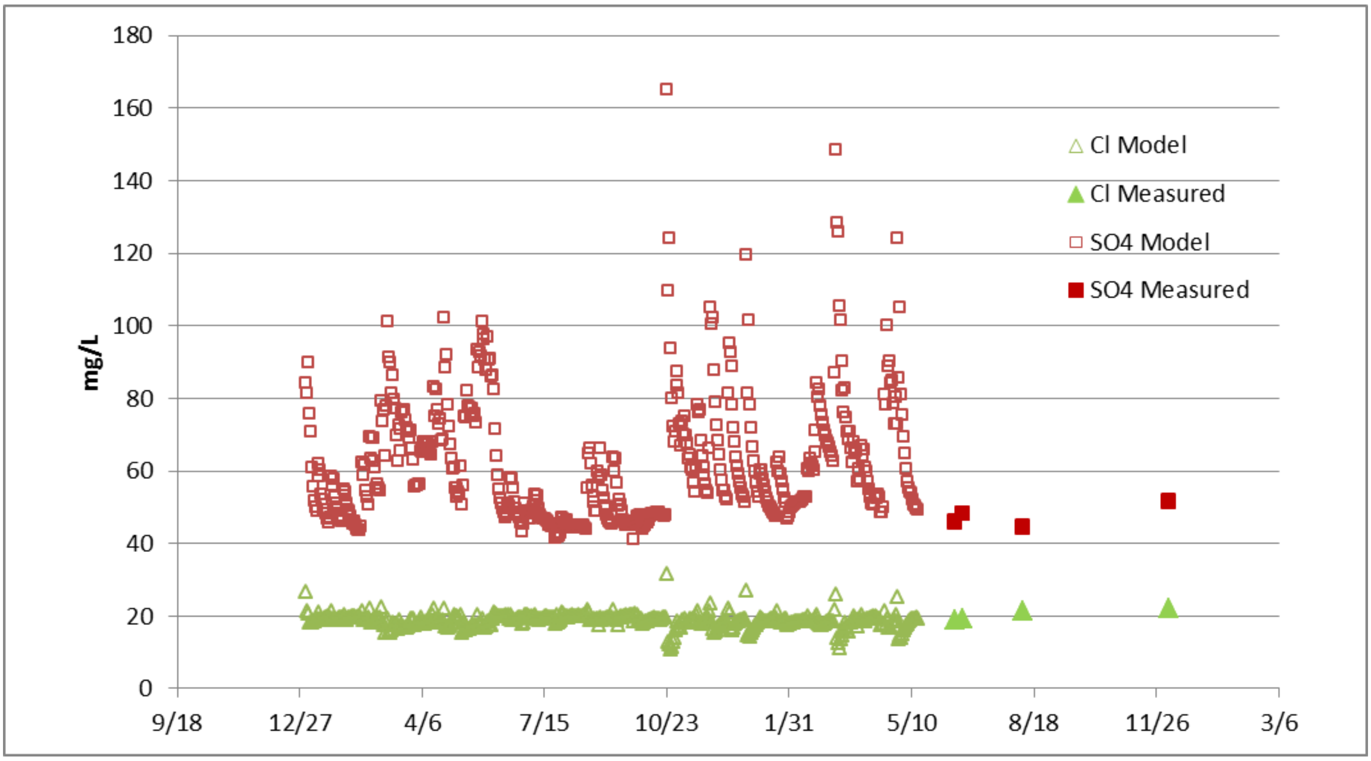

Figure 9 Chloride and Sulfate Predicted and Measured Concentrations

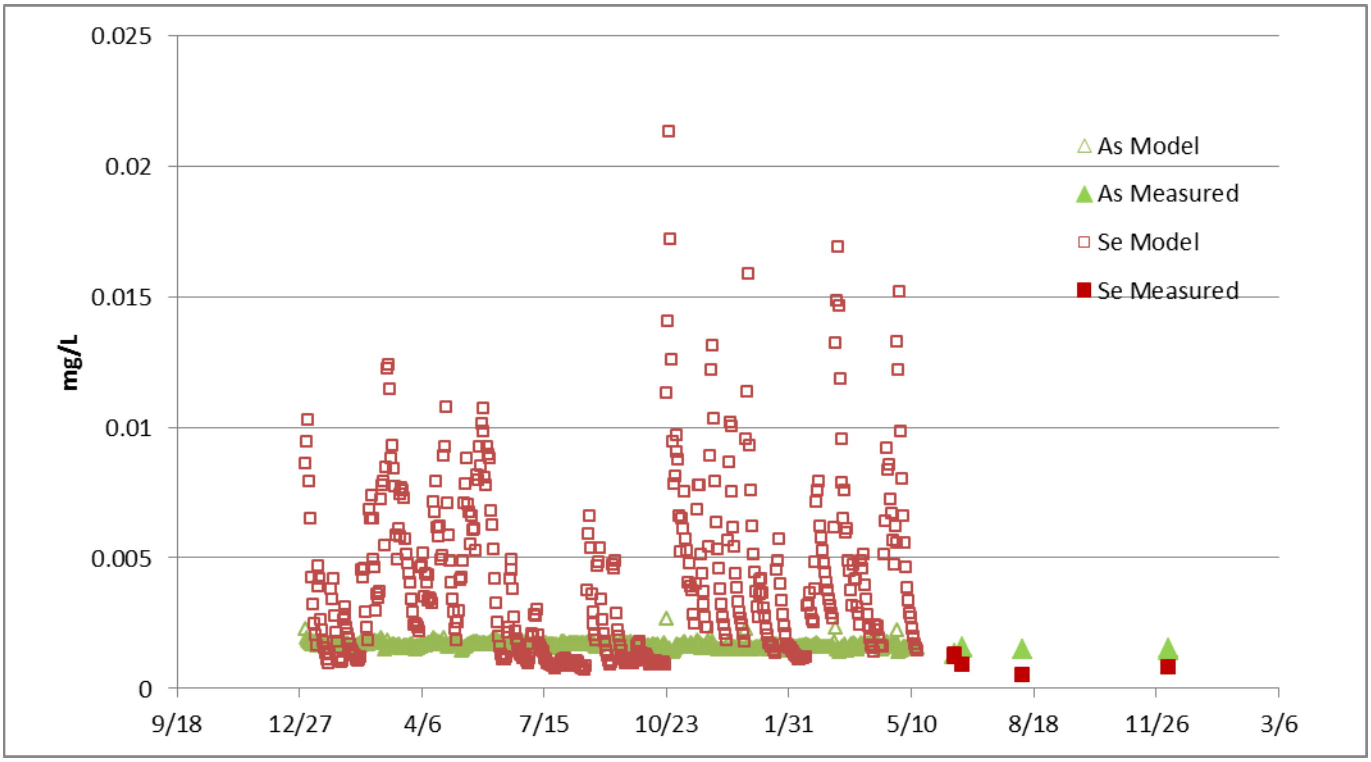

Figure 10 Arsenic and Selenium Predicted and Measured Concentrations

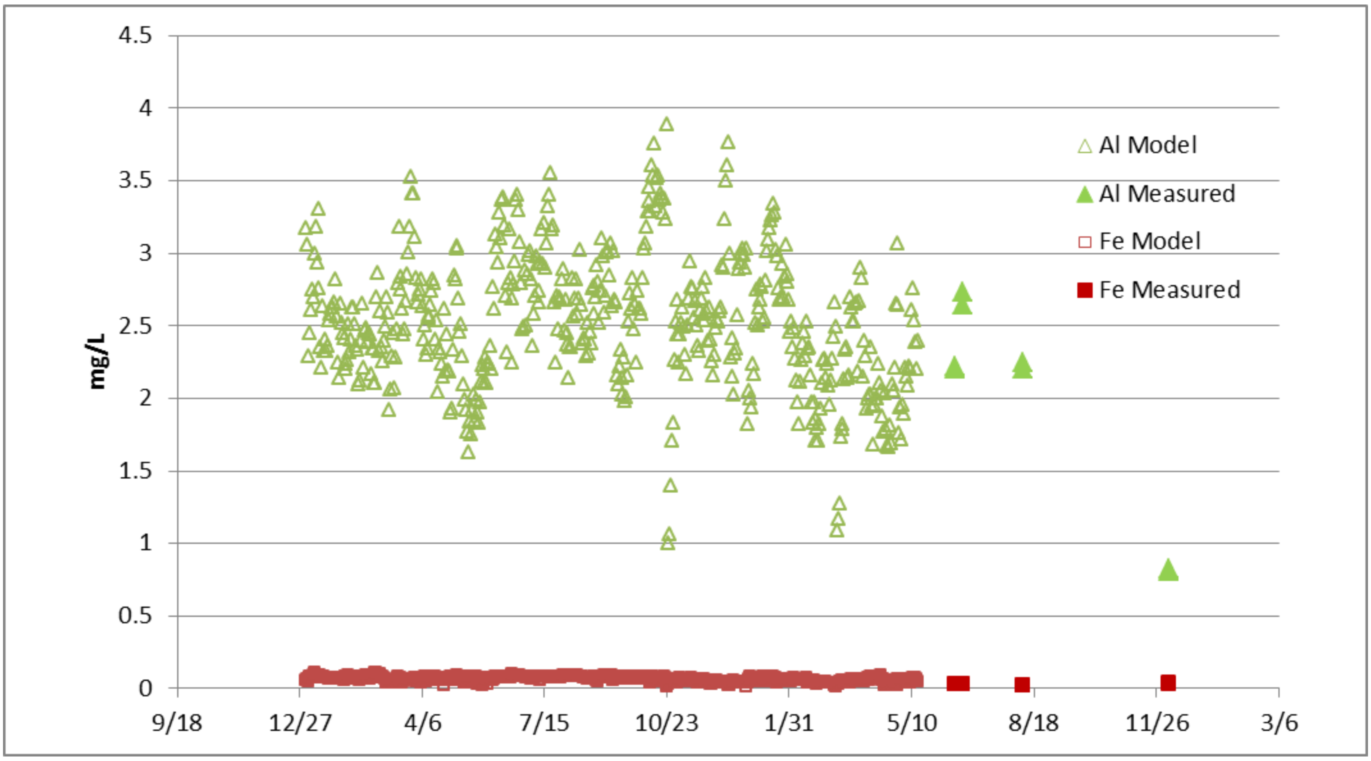

Figure 11 Aluminum and Iron Predicted and Measured Concentrations

Running the model without the ash containing streams simulates compliance with ELG requirements. Figure 12 and 13 shows the effect for arsenic and aluminum. The arsenic levels are only slightly reduced as there is minimal arsenic in bottom ash or economizer ash sluice water. However, the aluminum level is dramatically reduced without these sluice streams. Table 1 shows a summary of the difference in predicted concentrations in the effluent without the ash sluice streams included. Those substances primarily contributed by ash obviously show the greatest reduction. Other elements primarily present in the lake water show minimal changes.

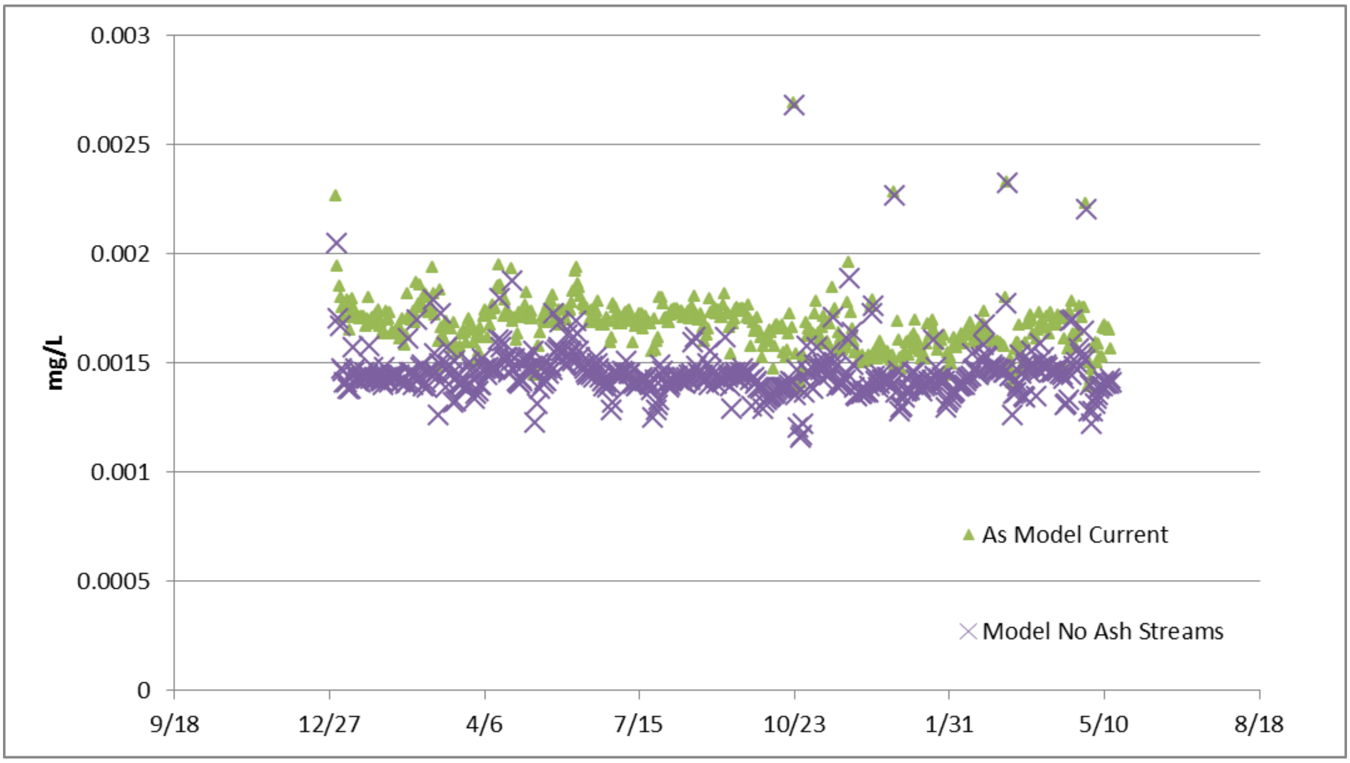

Figure 12 Arsenic Predicted Concentrations with and without Ash Sluice Streams

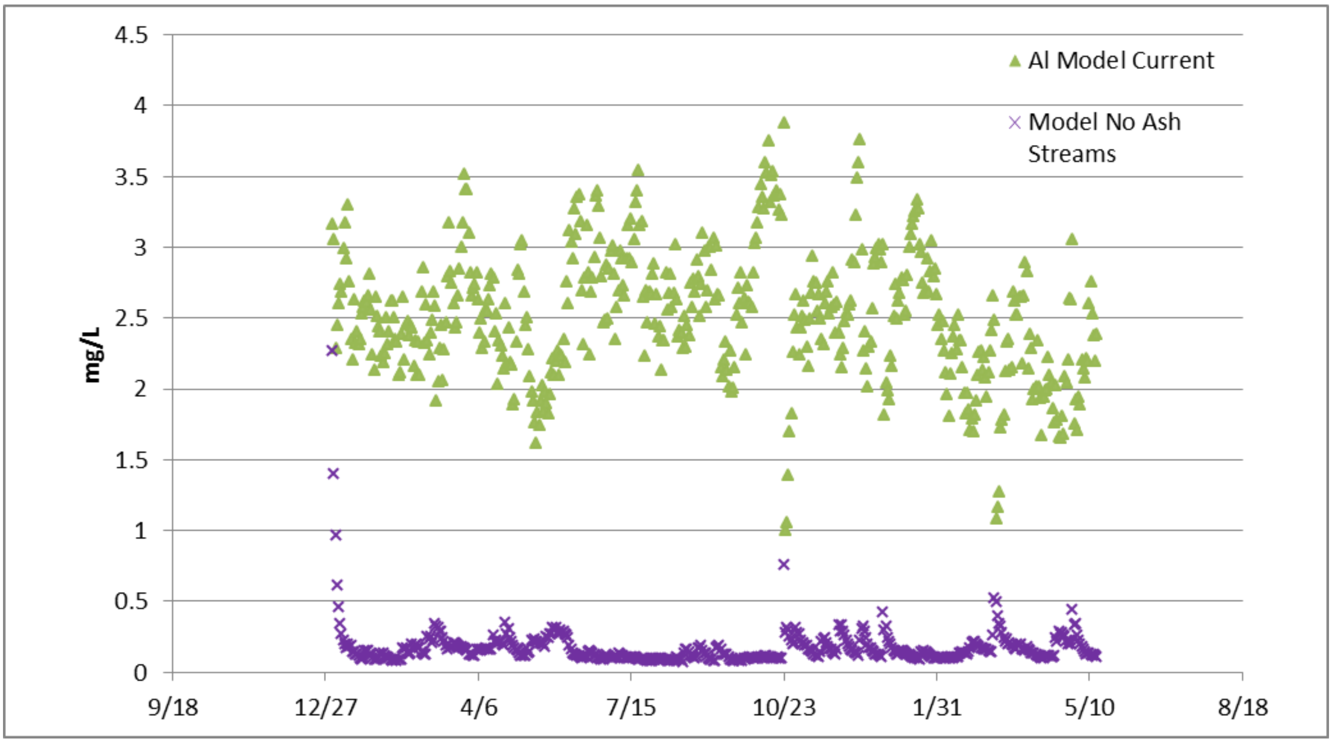

Figure 12 Aluminum Predicted Concentrations with and without Ash Sluice Streams

Table 1. Simulation Results Showing Effect of Removing Ash Sluice Streams from Other Low Volume Wastes (mg/L except pH)

Substance	Current Predicted With Ash Streams	Predicted W/O Ash Streams	Ratio No ash/Current
Ag	0.000016	0.000013	83%
Al	2.5	0.17	7%
As	0.0017	0.0015	87%
B	0.34	0.28	82%
Ba	0.24	0.15	60%
Be	0.000007	0.000007	95%
Br	0.14	0.15	101%
Ca	29	24	84%
Cd	0.000011	0.000006	56%
Cl	19	19	100%
Co	0.00013	0.00010	81%
CO3	104	107	103%
Cr	0.0039	0.0018	45%
Cu	0.0063	0.0056	90%
F	0.21	0.19	87%
Fe	0.0647	0.012	20%
Hg	0.000002	0.000002	100%
K	8.7	8.3	95%
Mg	4.9	4.9	101%
Mn	0.0410	0.0105	26%
Na	36	36	98%
NH3	0.19	0.19	102%
Ni	0.0020	0.0019	96%
NO3	0.44	0.46	104%
Pb	0.000057	0.000038	66%
pH	7.8	7.3	93%
Sb	0.00017	0.00015	85%
Se	0.0041	0.0035	84%
Si	0.14	0.14	100%
Sn	0.0019	0.0019	99%
SO4	62	60	96%
Sr	0.68	0.40	59%
Tl	0.00012	0.00003	23%
Zn	0.0045	0.0035	79%

CONCLUSIONS

GoldSim is a powerful modeling tool, with the capability of integrating PHREEQC to permit chemical substance interactions that mimic real world dynamic conditions. Using a relatively small number of samples for inlet streams, a wide ranging estimation of blended effluent compositions can be developed. Adding or deleting streams permits evaluation of various options for compliance strategies.