VI. INTEGRATED MODEL COMPARISON

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The integrated model evaluation and comparison process was conducted using information derived from the model evaluation questionnaire (Table 1) and surveys with individual model developers. Since the surface water regression model and the conceptual flowing water model are not fully developed for implementation, they were not included in the integrated model comparison. The assessment is centered on the models' ability to simulate pesticide fate and transport in the major environmental compartments (*e.g.*, field, groundwater, and surface water) and their impact on pesticide concentration in flowing water and a reservoir within a basin. The primary objective of the model evaluation is to assess the capabilities of each model and their potential use in FQPA drinking water assessments.

Basin Scale Hydrology

Each of the basin-scale models was developed to simulate overland flow and erosion from the field into receiving surface waters. Water balance within a basin is maintained in all the basin scale models. All models use the SCS curve number to control the water infiltration rates. Soil erosion is simulated using a modified soil erosion model (*e.g.*, MUSLE, USLE, *etc*.). BASINS (HSPF) and AnnAGNPS have the capability to estimate overland erosion processess as a function of sediment size distribution. Sediment transport and deposition processes are simulated in all models except RIVWQ. Sediment burial is simulated in SWAT and will be simulated in the modified PRZM-EXAMS linkage and SWAT. Sediment resuspension and settling is simulated in BASINS (HSPF) and will be in the modified PRZM-EXAMS linkage. It is noteworthy that basin scale models account for edge-of-field loading only and hence cannot account for surface water "runon-runoff" processes to and from adjoining fields.

Steady-state flow conditions of surface water is simulated in the modified linkage of PRZM-EXAMS and RIVWQ models. BASINS (HSPF) and SWAT can also simulate unsteady flow and this capability is currently being built into ne modified PRZM-EXAMS linkage. For purposes of the model evaluation, unsteady flow is defined as a condition where water flow depth can change as a function of time.

Each basin scale model can simulate tributaries feeding into a stream/river and then into a reservoir/lake. Delineation of the subbasins and watersheds in the models can be linked to GIS information is possible in BASINS (HSPF) and SWAT. It is noteworthy that SWAT and BASINS (HSPF) have a digital elevation model (DEM) to delineate topographic relief with the basin. Otherwise, delineation of subbasins or watersheds in a basin are indirectly derived from GIS or other outside data sources in the other models. The actual routing of runoff water from the field into adjoining surface water (stream or reservoir) is dependent on the discretization of watersheds within a basin. Each basin scale model can simulate tributaries feeding into a main flowing water body. First-order tributaries serve as the smallest streams contributing water routing in the basin scale models. The basin scale models are designed to route water from each watershed or subbasin as point source loadings into the higher order streams in the basin. Therefore, the runoff volume from each designated watershed or subbasin is representative of the fractional contribution of overland flow from different environmental factors and land management practices within the watershed.

All the basin models are designed to simulate streams or rivers as multiple stirred reactors. Simulation of the hydrology in a lake or reservoir is possible with all the models. The modified PRZM-EXAMS linkage will be the only model capable of simulating vertical stratification in surface water. Otherwise, similar to the nodes in the routing channel, the reservoir or lake is generally assumed to be a mixed reactor. For example, SWAT assumes that the water column and sediment are linked separate mixed reactors.

The simulation of groundwater (aquifer) is more difficult to evaluate because of ambiguity associated with definition of groundwater. For purposes of this evaluation, the groundwater compartment or "aquifer" is defined as the subsurface zone with complete water saturation. The subsurface hydrology in the SWAT model is complex because it accounts for macropore flow (preferential flow) coupled with subsurface lateral flow into surface water. BASINS (HSPF) also simulates lateral flow processes. In contrast, the pesticide leaching algorithms in RIVWQ and the modified PRZM-EXAM linkage are predominately designed to simulate vertical water movement using either a tipping bucket model in the root zone or Richard's equations in the vadose zone. AnnAGNPS does not simulate subsurface hydrology. The modified PRZM-EXAMS linkage addresses lateral transport by assuming that the mass of pesticide in leachate below the vadose zone is transported into surface water at a flow rate representative of the regional aquifer conductivity. The sophistication of the algorithms used to simulate lateral flow of groundwater in the various basin scale models in unclear.

Pesticide Environmental Fate and Transport Processes

The simulation of environmental fate and transport processes is similar among the basin scale models with the possible exception of plant-related dissipation processes (plant uptake, foliar interception, *etc*.) and spray drift. All the models can simulate fate and transport of organic hydrophilic and hydrophobic compounds. AnnAGNPS, BASINS (HSPF), and SWAT also can simulate the fate and transport of inorganic compounds. All the models can simulate multiple pesticides during a simulation.

All the models allow for simulation of pesticide runoff, degradation, and soil sorption for different soil types. BASINS (HSPF) is the only model which accounts for non-linear sorption using the Freundlich model. Otherwise, pesticide sorption is simulated using a linear K_d or K_{oc} model. In each model, pesticide extraction into runoff water is described using pesticide extraction algorithms from PRZM or GLEAMS. Pesticide degradation in soil is generally simulated as a cumulative degradation of competing abiotic and biotic processes. The modified PRZM-EXAMS linkage and RIVWQ, however, allow for biphasic degradation of the parent compound using linked first-order equations. The fate and transport of transformation products are only considered in the modified linkage of PRZM-EXAMS, RIVWQ, and BASINS (HSPF). Transformation product formation and degradation also can be simulated in the PRZM-EXAM linkage and RIVWQ. The sophistication of the transformation product degradation in BASINS (HSPF) is not clear from the evaluation.

Pesticide fate and transport in surface water is simulated in all the models. The level of sophistication, however, is different among the models. SWAT and RIVWQ use a single lumped degradation rate to represent pesticide degradation in surface water. In contrast, the modified PRZM-EXAM linkage and BASINS (HSPF) are designed to differentiate abiotic and biotic degradation. All the models account for pesticide sorption using a linear sorption model. BASINS (HSPF) also has the capability of representing non-linear sorption. All the models simulate pesticide volatilization from surface water. Pesticide fate and transport processes in groundwater are simulated in the modified PRZM/EXAMS linkage and SWAT. Pesticide degradation is described as a lumped first-order degradation process. Pesticide sorption is simulated using a linear model.

One-dimensional pesticide leaching is simulated in all models. Two-dimensional (leaching and lateral flow) pesticide movement is simulated in BASINS (HSPF), SWAT, and the modified PRZM-EXAMS linkage. As mentioned earlier, the sophistication of pesticide leaching subroutines in the models is difficult to assess because of the evaluation questionnaire did not separate root zone, vadose zone, and groundwater into distinct subsurface compartments.

Other routes of pesticide dissipation considered in the models are spray drift, foliar interception, foliar degradation, plant uptake, and volatilization. The modified linkage of PRZM-EXAMS and SWAT are capable of simulating spray drift. The spray drift subroutine in the modified PRZM-EXAMS linkage is not mechanistic because it assumes a fixed loss of pesticide drifts from the site into adjoining water bodies. The sophistication of the spray drift subroutines in SWAT cannot be addressed from this model evaluation. It is noteworthy that spray drift simulation in basin scale models may be upgraded using subroutines from the AgDRIFT model. Volatilization of pesticides is simulated in BASINS (HSPF), modified PRZM-EXAMS linkage, and RIVWQ.

The PRZM-EXAM linkage, RIVWQ, and SWAT are the only models that account for foliar interception, foliar wash-off, foliar degradation and plant uptake. PRZM-EXAMS and SWAT are the only models with crop production subroutines to simulate biomass production and crop yields.

Land Use and Management Practices

BASINS (HSPF) and SWAT have direct GIS linkages to soil type, management practices, crops, and drinking water utilities. In contrast, AnnAGNPS, the modified PRZM-

EXAMS linkage, and RIVWQ are designed to indirectly use GIS-type data. Automated databases on crops, soil, and meteorology also are available for all the models.

All the models are capable of simulating pesticide dissipation under most agricultural crop production systems (eg, orchards, pasture, row crops, small grains, fallow, and rotation). Also, HSPF and SWAT are capable of simulating pesticide dissipation from aquatic crop production systems, forests, or urban environments. SWAT is the only model capable of simulating the major crop management practices (*e.g*, irrigation, tillage practices, buffer strips, grassed waterways, terraces, and tile drains). However, the modified PRZM-EXAMS linkage and RIVWQ are capable of simulating irrigation and tillage effects on pesticide dissipation.

All the models except (BASIN) HSPF and SWAT can simulate banded pesticide application in the field. Broadcast, foliar applied, and soil incorporated pesticide application can be simulated in all models. Chemigation can be simulated by the modified PRZM-EXAM linkage and BASINS (HSPF). All the models are capable of varying application method with time.

Summary

The model evaluation process indicates that underlying algorithms for estimating pesticide fate and transport as well as hydrology appear to be very similar among the basin scale models. Major differences in model capabilities exist with the incorporation of a linkage between ground and surface waters, foliar dissipation processes for pesticides, crop growth simulation, plant uptake of pesticides, and simulation of crop management practices. Other notable model capabilities are GIS interfaces with various databases (including location of drinking water utilities) and model simulation capability of nonagricultural areas (eg, forest and urban areas).

Although the integrated model evaluation does not consider surface water regression models and the CFWRM, the group of models, *in toto*, provide a range of potential models for use in Tiered FQPA drinking water exposure assessment. The surface water regression model or the CFWRM are screening-level type models because they require few input parameters and are relatively simplistic. Alternative screening models may be constructed as meta-models of the mechanistic basin scale models. The modified PRZM-EXAMS linkage and RIVWQ may be potential Tier II models because they use PRZM as a runoff model. This model selection is consistent with Tier II modeling for aquatic exposure modeling. SWAT, BASINS (HSPF), and AnnAGNPS are viable Tier III type models because they are highly complex models which could limit routine use FQPA drinking water exposure assessments.