Cross-Cut Analysis of Crediting Models for Carbon/GHG, Water Quality and Water Quantity (2018)

CAPABILITIES – OUTPUTS

Quantification Model	Type (Empirical, Mechanistic)	Intended Region of Use (International; U.S.; Region; State)	Temporal Scale (Daily/Annual)	Spatial Scale (cropping/ag production areas, field/farm, HUC)	Carbon (Soil Organic Matter/Carbon Long-term Simulation, Nitrogen Fluxes, Enteric Fermentation, Manure)	Water Quality (Sediment, Phosphorus, Nitrogen, BOD, Pathogens, Salinity, Temperature, Algae, Toxics)	Water Quantity (Conserved Water Volume)	Soil Health (Y/N)	Hydrology: Groundwater Recharge (Y/N)	Hydrology: Flood Reduction (Y/N)	Hydrology: Streamflow (Y/N)	Hydrology: Streambank Erosion (Y/N)
Carbon/GHG Models												
DNDC *(DeNitrification-DeComposition)*	Mechanistic	Global	Daily	Field, Watershed	Plant Residue (*stable, labile and very labile*), Microbial Biomass (*labile and stable*), Humus and Passive-Humus (*stable and labile*); CO_2, CH_4, N_2O, NH_3 Fluxes	Nitrogen	Unknown	No	No	No	No	No
DAYCENT *(Daily Century Model)*	Mechanistic	North America	Daily	Field, Watershed	Soil Water Content and Temperature by layer, Plant Production and Allocation of Net Primary Production (NPP), Decomposition of Litter and Soil Organic Matter, Mineralization of Nutrients, N Gas Emissions from nitrification and denitrification, CH_4 Oxidation in non-saturated soils; Daily N-Gas Flux (N_2O, NO_x, N_2), CO_2 Flux from heterotrophic soil respiration	Nitrogen	Unknown	No	No	No	No	No
RothC *(Rothamsted Carbon Model)*	Mechanistic	TBD	Monthly	Field	Soil Carbon in each Pool and 14C, CO_2	No	No	No	No	No	No	No
PaSIM *(Pasture Simulation Model)*	Mechanistic	Europe	Hourly	Field	CO_2, CH_4, N20	TBD	TBD	TBD	No	No	No	No
AgroC	Mechanistic	TBD	Hourly, Daily	TBD	Soil Organic Carbon Pools, CO_2	TBD	TBD	TBD	No	No	No	No
ECOSSE *(Estimation of Carbon in Organic Soils – Sequestration and Emissions)*	Mechanistic	TBD	Daily, Monthly	Field, National	Soil Organic Carbon, Soil Greenhouse-Gas Emissions, Inert Organic Matter, Humus, Bomass, Resistant Plant Material, Decomposable Plant Material, CO_2, CH_4, N_2O, N_2	TBD	TBD	TBD	No	No	No	No
ORCHIDEE *(Organising Carbon and Hydrology in Dynamic Ecosystems)*	Mechanistic	Global	Daily	Watershed, Continental	Soil Carbon Dynamics, Litter Decomposition	TBD	TBD	TBD	No	No	No	No
Water Quality Models												
APEX *(Agricultural Policy/Environmental eXender)*	Mechanistic & Empirical	U.S.	Daily	Fields, Small Watersheds (HUC14-HUC12)	Soil Organic Carbon Long-Term Nitrogen* Carbon from Manure	Sediment Phosphorus Nitrogen	Yes	Yes	Yes	Yes	Yes	No
NTT *(Nutrient Tracking Tool with APEX)*	Mechanistic & Empirical	U.S.	Monthly, Annual	Fields, Small Watersheds (HUC14-HUC12)	None	Sediment Phosphorus Nitrogen	Yes	No	No	Yes	No	No
Snap-Plus *(WI Soil Nutrient Application Planner)*	Empirical*	Wisconsin	Annual	Field	None	Sediment Phosphorus	No	No	No	No	No	No
EPA Region 5 Calculator	Empirical	EPA Region 5	Annual	Field	None	Sediment Phosphorus Nitrogen	TBD	No	No	No	No	Yes
STEPL *(Spreadsheet Tool for Estimating Pollutant Load)*	Empirical	U.S.	Annual	Field	None	Sediment Phosphorus Nitrogen BOD *E. coli*	TBD	No	No	No	No	Yes
Nonpoint Source Nitrogen Calculation Spreadsheet; Nonpoint Source Phosphorus Calculation Spreadsheet (PA)	Empirical	Pennsylvania	Annual	Field	None	Sediment Phosphorus Nitrogen	TBD	No	No	Yes	No	Yes
SWAT *(Soil Water Assessment Tool)**	Mechanistic & Empirical	U.S.	Daily	Field, Watersheds (HUC8*)	Soil Organic Carbon; Long-Term Nitrogen Carbon from Manure	Sediment Phosphorus Nitrogen BOD Pathogens Salinity Temperature Algae	Yes	Yes	Yes	Yes	Yes	Yes
HSPF *(Hydrologic Simulation Program-FORTRAN*)*	Mechanistic & Empirical	U.S.	Hourly	Fields, Watersheds (HUC8*)	Nitrogen Fluxes	Sediment Phosphorus Nitrogen BOD Pathogens Salinity Temperature Algae Toxins	Yes	No	Yes	Yes	Yes	Yes
MIKE-SHE*	Mechanistic	Global	Sub-Hourly, Hourly*	Fields, Watersheds (HUC8*)	None	None	Yes	No	Yes	Yes	Yes*	Yes*
WARMF *(Watershed Analysis Risk Management Framework*)*	Mechanistic & Empirical	U.S.	Minutes, Hourly, Daily	Watersheds (HUC8*)	None	Sediment Phosphorus Nitrogen BOD Pathogens Salinity Temperature Algae Toxins Metals	Yes	No	No	No (?)	Yes	No (?)
NutrientNet (with APEX)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Virginia BMP Enhancement and land Conversion Offsets Calculations Worksheet (based on HSPF)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Quantity Models												
SWAP *(Statewide Agricultural Production Model)*	Mechanistic & Empirical	International	Hourly, Daily	Field	Some	Some	Yes	No	Yes	No	Yes	No
IDSCU *(Integrated Decision Support Consumptive Use Model)*	Mechanistic & Empirical	State (CO)	Daily, Monthly	Field	None	None	Yes	No	No	No	No	No
CROPWAT	Mechanistic & Empirical	International	Daily	Field	None	None	Yes	No	No	No	No	No
Custom Spreadsheet Model	Mechanistic & Empirical	Local	Daily, Monthly	Field	None	None	Yes	No	Yes	No	Yes	No

CAPABILITIES – AGRICULTURAL PRACTICE SIMULATION

Quantification Model	Vegetation Growth (Commodity Crops and/or Foliage Plants)	Animal Grazing (Cutting and Grazing Practices, Manure Management)	Multiple Cropping/Agricultural Production Systems (Y/N)	Field/Pasture Management BMPs (Y/N)	Tillage Practices (Y/N)	Irrigation Practices (Y/N)	Flooding Practices (Y/N)	Harvest Practices (Y/N)
Carbon/GHG Models								
DNDC	Grass, Crop, Forest	Cutting and Grazing Practices; Manure Management*	Yes	Yes	Yes	Yes	Yes	Yes
DAYCENT	Crop, Grass, Forest, Savannah	Grazing, Cultivation, Fire, Organic Matter/Fertilizer Addition	Unknown	Yes	Yes	Yes	Unknown	Yes
RothC	Grassland, Woodland	Indirectly	Indirectly	Indirectly	Indirectly	Indirectly	Indirectly	Indirectly
PaSIM	Pasture, Grassland	Cutting and Grazing Practices; Manure Management	TBD	TBD	TBD	TBD	TBD	TBD
AgroC	Agricultural Systems	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ECOSSE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ORCHIDEE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Water Quality Models								
APEX	Commodity Crops and Foliage Plants	Cutting and Grazing Practices; Manure Management	Yes	Yes	Yes	Yes	TBD	Yes
NTT	Commodity Crops and Foliage Plants	Cutting and Grazing Practices	Yes	Yes	Yes	Yes	TBD	Yes
Snap-Plus	No	Manure Management	Yes	Yes	Yes	Yes	TBD	Yes
EPA Region 5 Calculator	No	Manure Management	No	Yes	Yes	No	TBD	No
STEPL	No	Manure Management	No	Yes	Yes	No	TBD	No
Nonpoint Source Nitrogen/Phosphorus Calculation Spreadsheet (PA)	No	Manure Management	No	Yes	Yes	No	TBD	No
SWAT	Commodity Crops and Foliage Plants	Cutting and Grazing Practices; Manure Deposit	Yes	Yes	Yes	Yes	Unknown	Yes
HSPF	Commodity Crops and Foliage Plants	Cutting and Grazing Practices; Manure Deposit; Manure Management	Yes	Yes	Yes	Yes	Unknown	Yes
MIKE-SHE*	No	No	No	No	No	Yes	Unknown	No
WARMF	No	No	No	No	No	Yes (?)	Unknown	No
NutrientNet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Virginia BMP Enhancement and land Conversion Offsets Calculations Worksheet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Quantity Models								
SWAP	Yes	TBD	TBD	TBD	No	Yes	TBD	Yes
IDSCU	Yes	TBD	TBD	TBD	No	Yes	TBD	Yes
CROPWAT	Yes	TBD	Yes	TBD	No	Yes	TBD	Yes
Custom Spreadsheet Model	Yes	TBD	Yes	TBD	No	Yes	TBD	Yes

INPUT REQUIREMENTS, MODEL VALIDATION, MODEL CALIBRATION, REQUIRED LINKAGES

Quantification Model	Input Data Needs	Input Data Availability (L/M/H)	Expertise Required to Run Model (L/M/H)	Model Validation: Expertise Required to Validate Model (L/M/H)	Model Calibration Data Needs	Calibration Data Availability	Level of Effort to Calibrate Model (L/M/H)	REQUIRED LINKAGES TO ADDITIONAL MODELS OR DATABASES (Y/N; if Yes, ease-of-use with APIs)
Carbon/GHG Models								
DNDC	Moderate	Low, Moderate	Low, Moderate	Moderate, High	crop yield, N_2O emissions, soil C sequestration and soil water	Crop yield and soil water are likely easily available; emission data may be difficult to find	Low, Moderate	No
DAYCENT	Moderate	Low, Moderate	Moderate, High	Moderate, High	Crop Yield, Soil Water Content, Soil Emissions	Crop yield and soil water are likely easily available; emission data may be difficult to find	Moderate, High	No
RothC	Low	Moderate, High	Low	Low	TBD	TBD	TBD	TBD
PaSIM	Moderate	Low, Moderate	TBD	TBD	TBD	TBD	TBD	TBD
AgroC	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ECOSSE	Unknown	TBD	TBD	TBD	TBD	TBD	TBD	TBD
ORCHIDEE	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Water Quality Models								
APEX	Extensive (*Tools are available to prepare the data*)	High	High	High	Local hydrology and water quality data	Dependent on local availability	High	No
NTT	Extensive (*Requires minimum effort with NTT's web interface*)	High	Low	High	Local hydrology and water quality data	Dependent on local availability	TBD	No
Snap-Plus	Moderate (*Requires less effort with program's web interface*)	High for Wi; Low for other states	Moderate	High	Local sediment and nutrient loading data (*calibration not needed for WI*)	Dependent on local availability (calibration not needed for WI)	Moderate (*Calibration not required for WI*)	No
EPA Region 5 Calculator	Low	High	Low	High	No Model Calibration Required	No Model Calibration Required	No Model Calibration Required	No
STEPL	Low	High	Low	High	No Model Calibration Required	No Model Calibration Required	No Model Calibration Required	Yes (*good ease-of-use*)
Nonpoint Source Nitrogen/Phosphorus Calculation Spreadsheet (PA)	Low	High	Low	High	No Model Calibration Required	No Model Calibration Required	No Model Calibration Required	No
SWAT	Extensive (*GIS-based tools, e.g., ArcSWAT available for data preparation*)	High	High; Moderate with HAWQS modeling system	High	Local/regional hydrology and water quality data	Dependent on local/regional availability	High	No
HSPF	Extensive (*Tools available for the Chesapeake Bay watershed; USEPA's BASINS modeling system available for all U.S.*)	High	High	High	Local/regional hydrology and water quality data	Dependent on local/regional availability	High	No
MIKE-SHE*	Extensive	Moderate	High	High	Local/regional hydrology data	Dependent on local/regional availability	High	Yes (*MIKE-Hydro River stream hydraulic model; ease-of-use with APIs unclear*)
WARMF	Extensive (*Can use USEPA's BASINS modeling system, available for all U.S*)	High	High	High	Local/regional hydrology and water quality data	Dependent on local/regional availability	High	Yes (*Requires input for non-point source loads; ease-of-use with APIs unclear*)
NutrientNet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Virginia BMP Enhancement and land Conversion Offsets Calculations Worksheet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Quantity Models								
SWAP	Variable	Moderate	Moderate	Moderate	N/A	N/A	N/A	No
IDSCU	Limited	High	Low	Low	N/A	N/A	N/A	No
CROPWAT	Limited	High	Low	Low	N/A	N/A	N/A	No
Custom Spreadsheet Model	Variable	Depends	Low	High	N/A	N/A	N/A	No

PRIOR MARKET APPLICATIONS, UNCERTAINTY, MODEL TRANSPARENCY, MODIFIABILITY, AND SUPPORT, NOTES

Quantification Model	PRIOR MARKET APPLICATIONS	ESTIMATE OF UNCERTAINTY IN MODEL OUTPUTS (L/M/H)	Clear Versioning of Model (Y/N)	Peer-Reviewed Documentation (Y/N)	Original Developers	Developer Accessibility (L/M/H)	Developer Responsiveness (L/M/H)	Open Source (Y/N)	Third-Party Add-ons (Y/N)	User Community Activity (L/M/H)	NOTES(*)	Suggested Addition: Tile Drainage (Y/N)
Carbon/GHG Models												
DNDC	ACR (*Used in rice CH4 and cropland N2O management projects*); CDM (*used in rice protocol*); NCGA/Monsanto (*used in carbon insetting framework*)	Unknown (*Uncertainty analysis can be performed*)	Yes	Yes	Univserisity of New Hampshire	Low	TBD	Yes	No	Low*	Specific grazing/manure management practices include: # Grazing/Cutting Applications, Livestock Type, Grazing Hours/Day and Stocking Rate, Type of Manure, # Applications, C/N Ratio of ManureUser Community: http://www.globaldndc.net/information/about-us-i-1.html	
DAYCENT	ACR (*Proponents run DayCent for ACOGS projects*) CAR (*used to develop default emission factors for grasslands protocol*)*	TBD	Yes	Yes	Colorado State University	Moderate	TBD	Yes	No	TBD	Also used in COMET calculators	
RothC	VCS (*Proponents run RothC for SALM projects*)	No Uncertainty Analysis	TBD	Yes	Rothamsted Research, UK	High	TBD	Yes	TBD	TBD		
PaSIM	CarboEurope IP, NitroEurope IP, CARBO-Extreme* (*European*) CLIMATOR, VALIDATE* (*French*)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Research projects aiming at understanding the C and N cycles, carbon sequestration, greenhouse gases emissions (GHG) and the effects of climate variability and climate change.	
AgroC	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD		
ECOSSE	TBD	TBD	TBD	TBD	University of Aberdeen, Scotland, UK	TBD	TBD	TBD	TBD	TBD		
ORCHIDEE	TBD	TBD	TBD	TBD	LMD, LSCE, LGGE	TBD	TBD	TBD	TBD	TBD		
Water Quality Models												
APEX	Vermont Phosphorus Protocol	Low (*if calibrated properly*)	Yes	Yes	J.R. Williams, et al., Blackland Research and Extension Center, Texas AgriLife Research and USDA-NRCS, Temple, TX	TBD	TBD	Yes	No	Low	Long-Term Nitrogen modeled using equations from the CENTURY model	Yes
NTT	Iowa Nutrient Reduction Exchange (*Model currently under consideration*)	High (*calibration effort ongoing*)	No	Yes	Ali Saleh, et al., Texas Institute for Applied Environmental Research, Tarleton State U., Stephenville, TX	TBD	TBD	No	No	Low	Soil Health and Carbon outputs can be added	Yes
Snap-Plus	Wisconsin Water Quality Trading Program	Low to Moderate for WI; High for other states	Yes	No	Laura Ward Good, et al., U of WI-Madison	TBD	TBD	TBD	No	High	Underlying models: RUSLE2 and P Index	No
EPA Region 5 Calculator	Michigan Trading Rules	High	Yes	No	USEPA through Tetra Tech, Inc.	TBD	TBD	Yes	No	TBD		No
STEPL	Great Miami River, EPRI Ohio River Pilot, Iowa Nutrient Reduction Exchange	High	Yes	No	USEPA through Tetra Tech, Inc.	TBD	TBD	Yes	No	TBD	These three models/tools are fundamentally similar in 1) underlying runoff (TR55 CN method) and soil erosion (RUSLE) models; and 2) tool user interface (spreadsheets)	No
Nonpoint Source Nitrogen/Phosphorus Calculation Spreadsheet (PA)	Pennsylvania Nutrient Trading Program	High	No	No	PA Department of Environmental Protection	TBD	TBD	Yes	No	TBD		No
SWAT	Trading Feasibility Study in the Great Miami River, OH	Low (*if calibrated properly*)	Yes	Yes	J. G. Arnold, et al., USDA-ARS Grassland, Soil, and Water Research Lab, Temple, TX	High	High	Yes	Yes	High	SWAT used in water quality feasibility study but not in crediting; Larger watersheds can be modeled by connecting individual simulated HUC8's	Yes
HSPF	Nutrients in Chesapeake Bay Watershed states (e.g., VA); Bacteria in Big Sioux River (SD, MN, IA)	Low (*if calibrated properly*)	Yes	Yes	T. Donigian, B. Bicknell, et al., Aqu Terra Consultants / RESPEC, SD	Moderate	Moderate	Yes	Yes	Low	HSPF not used in crediting application; Larger watersheds can be modeled by connecting individual simulated HUC8's or smaller watersheds; Additional water quality pollutant reduction outputs can be added as a parameter for users	No
MIKE-SHE*	None	Low (*if calibrated properly*)	Yes	Yes	Danish Hydraulic Institute (*private software & engineering firm*)	Unknown	Unknown	No (*proprietary*)	No	Unknown	MIKE-SHE is a hydrologic model with no prior market application; Spatial scale should be limited only by computing power; Time-step is adaptive; Streamflow and Streambank Erosion modelling linked Mike-Hydro River model	No (but probably can be accommodated with some model modification)
WARMF	EPRI Ohio River Basin Trading Pilot (*for nutrient attenuation factor determination*)	Low-moderate (if calibrated properly)	Yes	Yes	Systec Water Resources, Inc. (*funded by EPRI*)	Unknown	Unknown	No (*software publicly available, model code probably not*)	No	Low	WARMF used for calculating nutrient attenuation factor but not crediting; Larger watersheds can be modeled by connecting individual simulated HUC8's	No (but probably can be accommodated with some model modification)
NutrientNet	Pennsylvania Nutrient Trading Program (*Prior*); Kalamazoo River Water Quality Trading (*Prior*)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**Model not further assessed due to the model's: 1) main functions having been replaced by NTT; 2) limited availability for only 4 watersheds in 5 states; and 3) lack of updates (last update was probably in 2007) (http://www.nutrientnet.org/)**	N/A
Virginia BMP Enhancement and land Conversion Offsets Calculations Worksheet	Chesapeake Bay Watershed Nutrient Credit Exchange Program (Virginia)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**Model not further assessed as the worksheet reflects the results from a HSFP model (the Chesapeake Bay Model v. 4.3)**	N/A
Water Quantity Models												
SWAP	None Known	Moderate	Yes	Yes	Wagenigen University (Netherlands)	TBD	Unknown	No	No	Low		
IDSCU	CO Water Rights Transfers	Low	Yes	Yes	Colorado State University	TBD	Unknown	No	No	None		
CROPWAT	None known	Low	Yes	Yes	FAO	TBD	Unknown	No	No	Low		
Custom Spreadsheet Model	Extensive history of Water Transfers	Varies	N/A	No	N/A	N/A	N/A	Yes	No	None		

Legend: Model either: 1) is related to WQT but does not currently have a WQT crediting application OR 2) has a WQT crediting application but was not assessed in this analysis (further explained in the model's notes column)

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