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Microservices for Computing Nutrient Loss Potentials and Pesticide Hazard Ratings and their Mitigation on Agricultural Land

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Abstract: The Stewardship Tool for Environmental Performance (STEP) is an expert system enabling the assessment of resource conservation benefits of management techniques and conservation practices applied to agricultural land. The STEP water quality module (WQM) computes nutrient leaching and runoff potentials, sediment runoff potentials, pesticide leaching and runoff potentials, as well as pesticide hazard ratings for farm fields based on local conditions. From this WQM computes minimum threshold levels reflecting the level of treatment needed to mitigate the loss potentials and hazards. The tool then provides a process for applying mitigating technique and practice scores to meet or exceed thresholds. The nutrient component of WQM results from analysis of the millions of Agricultural Policy EXtender (APEX) model simulations used in the USDA Conservation Effects Assessment Program (CEAP) completed for the major river basins of the United States since 2002. CEAP estimated the environmental benefits of conservation practices at the river basin level and in 2011 incorporated the knowledge into WQM. The pesticide component of WQM results from more than two decades using the Pesticide Screening Tool, a screening procedure developed from results from Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) simulations. As part of the effort to integrate resource assessment at the farm field level, we describe a suite of 22 microservices supporting the WQM workflow. We make these services available through the OMS/CSIP continuous integration process.

***Keywords**:* nutrient loss; pesticide hazard; microservices

1.0 Introduction

Farming operations in the United States continue to increase their productive capacity while minimizing inputs and their cost, as well as working to ensure the long-term sustainability of the soil and water resources on agricultural land. Optimizing nutrient and pest management to crop need lowers cost and promotes sustainability. The USDA Natural Resources Conservation Service (NRCS) conceived and developed the Stewardship Tool for Environmental Performance (STEP) for, among other resource concerns, assessing water quality management on farm fields (Norfleet et al, 2015) as part of technical assistance provided daily by field conservationists in county-level offices. The STEP water quality module (WQM) captures knowledge gained from extensive agro-ecosystem modelling and water quality subject matter experts working in this domain.

WQM applies lessons learned in the agency Conservation Effects Assessment Project (CEAP) initiated in 2002 to analyse conservation practice effects on soil and water quality in the 18 major river basins of the county. CEAP made extensive use of the Agricultural Policy EXtender (APEX) model (Gassman et al, 2010) to compute edge-of-field losses of sediment and nutrients for the many thousands of sample points in each basin. From these analyses, conservation planning and agronomic technical experts established and tested soil loss potential (vulnerability) classes for

nitrogen runoff and leaching, phosphorus and sediment runoff (Chan et al, 2017). They established vulnerability mitigation thresholds, and mitigation values to techniques and practices for meeting or exceeding thresholds.

WQM incorporates processes and algorithms (Goss and Wauchope, 1990) deployed in the Pesticide Screening Tool (PST), a desktop application used by field conservationists for several years (USDA-NRCS, 2009). The screening procedure was developed from modelling using the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard et al, 1987). PST provides soil, pesticide, and soil-pesticide interaction loss potential classes for leach, solution runoff, and adsorbed runoff. These feed into pesticide hazard rating classes for the three loss pathways, also including pesticide drift. Agency technical specialists also established mitigation thresholds, and mitigation values for levels of integrated pest management (IPM), techniques and practices for meeting or exceeding thresholds to complete the WQM process.

Recently NRCS allocated resources to automate WQM processes for integrating into their next generation national program delivery information system, as well as make them available for external partner applications.

2.0 Methods

The design for WQM automation separates science and technical expertise processes and data from those involving transactions to store and manage specific customer or project files, enabling multiple software applications to use the underlying science and knowledge. We design WQM processes to be highly granular, a suite of microservices contained in a web service layer having common libraries. Should the need arise, with relatively minor effort microservices can be reconstituted into less granular services to suit a particular application requirement. The microservice architecture pattern we use enables continuous refactoring and deployment. Figure 1 displays data flows expected for an application using WQM services.

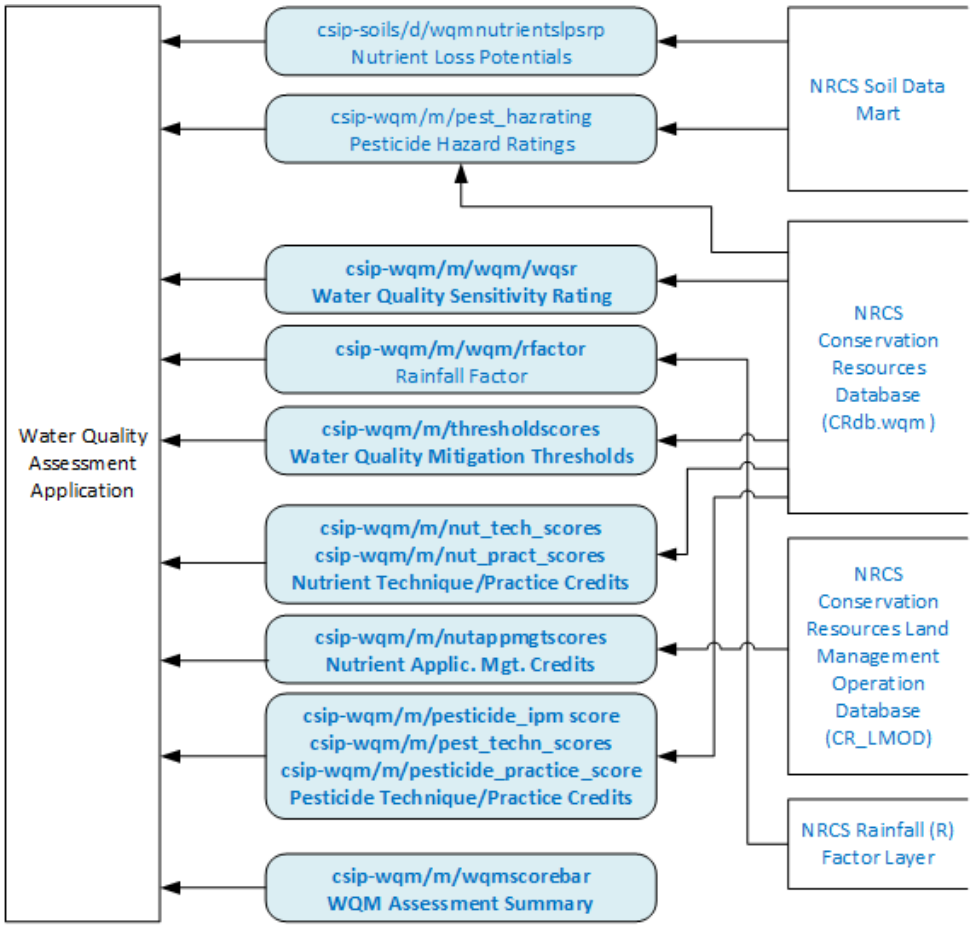

Figure 1. WQM data flows

WQM microservice development leverages the Object Modeling System (OMS) and Cloud Services Integration Platform (CSIP) application programming interfaces (APIs) for model and data as-a-service implementations (David et al, 2014). CSIP services are RESTful, consuming request JSON populated by an application and returning results as response JSON to the application supporting the business workflow. We build, test, and deploy CSIP services using our DevOps process involving Mecurial repositories, Jenkins-based continuous integration, and Docker/Kubernetes container cluster management (David et al, 2016). WQM service descriptions and endpoints are published and available at: https://alm.engr.colostate.edu/cb/item/13578.

We manage WQM domain data as a schema in a greater Conservation Resources (CRdb) domain database. Current WQM tables supporting loss potential and hazard ratings, as threshold levels and scoring include:

d_wqm_water_quality_sensitivity_rating (contains geometry)
d_wqm_soil_pest_interaction_leaching
d_wqm_soil_pest_interaction_solutrion_runoff
d_wqm_soil_pest_interaction_adsorbed_runoff
d_wqm_pesticide_hazard_potential
d_wqm_threshold_levels
d_wqm_nutrient_technique_credits
d_wqm_sediment_nutrient_practice_credits
d_wqm_nutrient_application_management_credits
d_wqm_ipm_credits
d_wqm_ipm_technique_credits
d_wqm_ipm_practice_credits

WQM domain data also includes pesticide product, formula, active ingredient, chemical, and toxicity data from the U.S. Environmental Protection Agency (EPA) and other sources, integrated, managed, and updated 1-2 times annually by NRCS data stewards. Figure 2 displays the current WQM pesticide domain tables. Essentially each pesticide product has a formula of active ingredients. Each active ingredient has chemical properties, as well as properties for toxicity to humans and fish.

In addition, WQM web services rely on other sources of data: the NRCS Rainfall (R) Factor layer, the NRCS Soil Data Mart (https://sdmdataaccess.nrcs.usda.gov), and crop parameter data in the NRCS Conservation Resources Land Management Operations Database (CR_LMOD).

3.0 WQM Microservice Descriptions

Two web service layers, csip-soils and csip-wqm, support the WQM workflow. The first part of the WQM workflow involves assessing conditions on the farm field: nutrient soil loss potentials, loss potentials for the pesticides applied in the cropping system, soil-pesticide interactions, and pesticide hazards to humans and fish. These outputs feed into determining the level of treatment necessary to reduce losses and hazard

Computing nutrient and pesticide soil loss potentials require soil parameters from the NRCS Soil Data Mart (SDM): taxonomic order, hydrologic soil group, erodibility (K) factor, slope steepness, coarse rock fragment volume, and water table kind. The following service intersects SDM soil mapunit geometry with farm field geometry, builds a list of valid soil components and their percentages in the farm field, and fetches the required parameters for each component.

http://csip.engr.colostate.edu:8083/csip-soils/d/wqmsoilparams/2.0

For computing nutrient soil loss potentials, the first of the next two services computes nutrient leaching potential for each valid soil component in the farm field using soil vulnerability algorithms developed during the CEAP project (USDA-NRCS, 2012). The second service computes soil component nutrient and sediment runoff potentials. Both services return weighted average loss potentials for the farm field, which are used later to produce soil-pesticide interaction ratings.

http://csip.engr.colostate.edu:8083/csip-wqm/m/nutrient_slp/2.0
http://csip.engr.colostate.edu:8083/csip-wqm/m/scsednut_srp/2.0

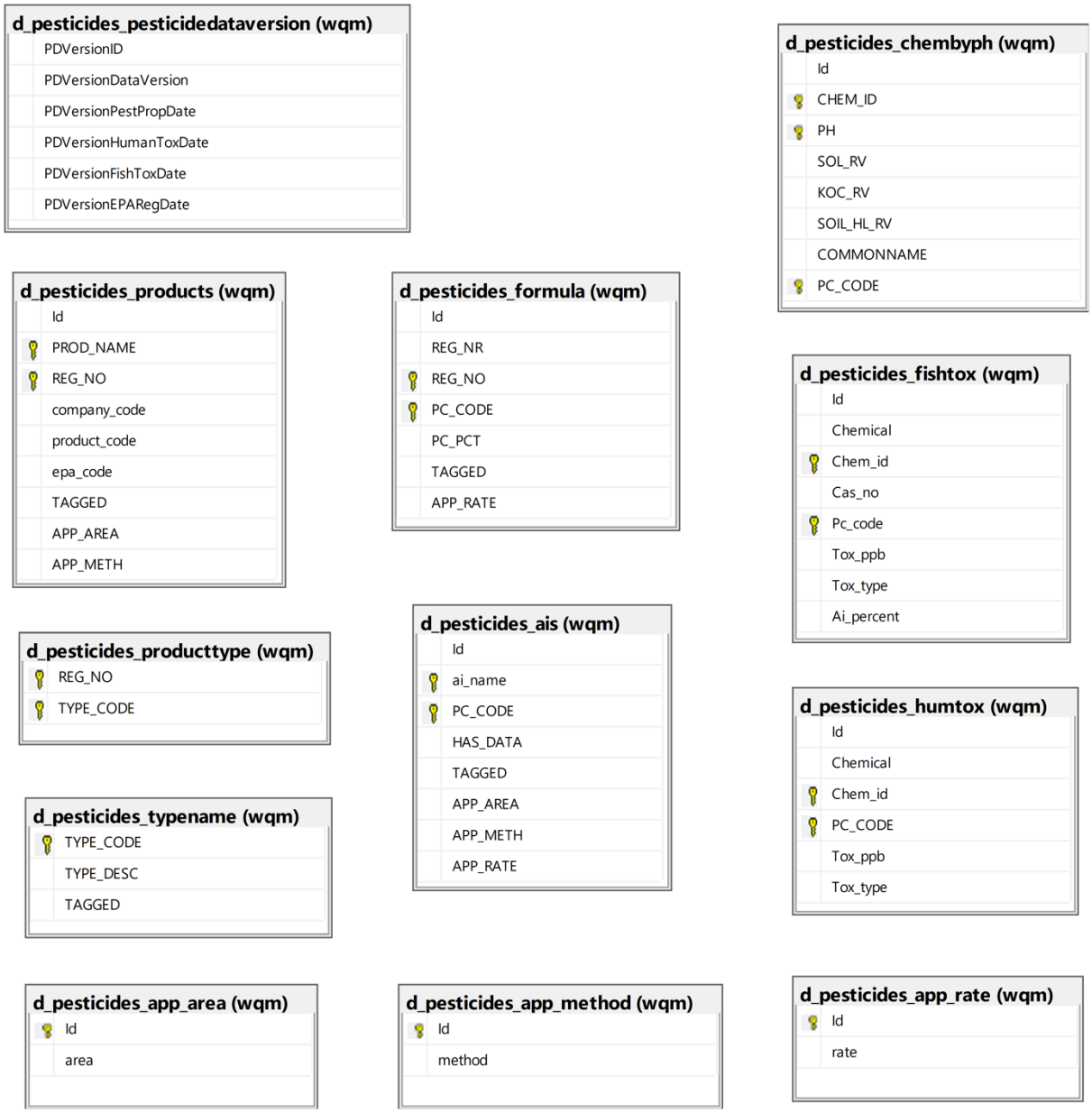

Figure 2. WQM Pesticide Data Tables.

We designed WQM services to be highly granular, recognizing they could be combined into another service to meet a particular application requirement. The following service combines the three services above to support the NRCS Resource Stewardship application. The service request provides farm field geometry and the combination service returns the soil component list, the relevant soil parameters, and computed leaching and runoff loss potentials. The service response includes the results from the previous two services.

http://csip.engr.colostate.edu:8083/csip-soils/d/wqmnutrientslpsrp/2.0

Computing pesticide-related loss potentials requires a list of the pesticides applied in the cropping system, including application method, area, and rate inputs. The first of the following services returns a list of pesticide products and their active ingredients filtered by product name, EPA registration number, or other search criteria. The second service returns loss potential of each pesticide active ingredient to leaching, solution runoff, and adsorbed runoff. The service also returns parameters to be used later for computing pesticide hazard ratings.

http://csip.engr.colostate.edu:8083/csip-wqm/m/wqm/pestprodlist/2.0

http://csip.engr.colostate.edu:8083/csip-wqm/m/pestlosspot/2.0

The following three services compute the loss poteRntials of soil components for pesticide leaching (slp), runoff in solution (ssrp), or runoff adsorbed to sediment (sarp). Service requests include a list of valid soil components in the farm field and the soil parameters necessary for computing the loss potentials. The service also returns weighted loss potentials for the farm field.

http://csip.engr.colostate.edu:8083/csip-wqm/m/pesticide_slp/2.0
http://csip.engr.colostate.edu:8083/csip-wqm/m/pesticide_ssrp/2.0
http://csip.engr.colostate.edu:8083/csip-wqm/m/pesticide_sarp/2.0

Once pesticide loss potentials and soil loss potentials have been computed, the next service queries relevant CRdb.wqm tables and returns soil-pesticide interaction ratings for leaching, solution runoff, and adsorbed runoff, for each pesticide applied in the cropping system for the farm field. The service request includes farm field soil loss potentials and pesticide loss potentials.

http://csip.engr.colostate.edu:8083/csip-wqm/m/soilpestlosspot/2.0

Finally, the next service produces ratings for hazard to humans and fish, for leaching, solution runoff, and adsorbed runoff (fish only), for each pesticide applied in the cropping system of the farm field. The inputs to the service include soil-pesticide interaction ratings and pesticide parameters relevant to toxicity to humans and fish. The service also returns representative pesticide hazard ratings for the entire farm field, the ratings for the most hazardous pesticide applied in the cropping system.

http://csip.engr.colostate.edu:8083/csip-wqm/m/pest_hazrating/2.0

As was done for nutrient loss potentials above, we combined the pesticide loss potentials, interaction rating, and hazard rating services into one to support the NRCS Resource Stewardship application. The inputs to the following service include farm field geometry and the pesticides applied in the cropping system for the farm field. The service returns pesticide loss potentials, pesticide soil loss potentials, soil-pesticide interaction ratings, and pesticide hazard ratings

http://csip.engr.colostate.edu:8083/csip-wqm/m/wqm/rs_pest_hazrating/1.0

With the assessment of nutrient and pesticide loss potentials and pesticide hazard completed, the next WQM step involves setting thresholds for mitigating losses and hazards. The first step determines whether the farm field is located in a Sensitive or Critical water quality priority area. NRCS intends these areas to be defined as a participatory, consensus-building process involving partners and stakeholders. The areas will be managed in water quality sensitivity rating (WQSR) spatial layer by NRCS state-level data stewards.

The following web service intersects WQSR geometry with the farm field centroid returning a rating of Base, Sensitive, or Critical.

http://csip.engr.colostate.edu:8083/csip-wqm/m/wqm/wqsr/1.0

The second step towards establishing a mitigation threshold factors in precipitation. The following service intersects the NRCS rainfall factor spatial layer with the farm field centroid, returning the R factor, from the climate component of the Revised Universal Soil Loss Equation (RUSLE2), which reflects both precipitation amount as well as intensity.

http://csip.engr.colostate.edu:8083/csip-wqm/m/wqm/rfactor/1.2

With WQSR and R factor results, plus nutrient loss potentials and pesticide hazard ratings from previous services, the next service returns mitigation threshold levels for:

Nitrogen leaching, runoff
Phosphorus runoff
Sediment runoff
Pesticide hazard to humans for leaching, solution runoff, drift

Pesticide hazard to fish for leaching, solution runoff, and adsorbed runoff, drift

http://csip.engr.colostate.edu:8083/csip-wqm/m/thresholdscores/1.0

WQM arbitrarily sets a default mitigation threshold level for pesticide drift, subject to consensus expert facilitated adjustment. NRCS data stewards manage mitigation threshold levels maintained in the CRdb.wqm.wqm_threshold_scores table, and over time thresholds can be adjusted to reflect updated knowledge.

With mitigation threshold levels established, applications using WQM services can choose treatments to include in recommendations and plans for meeting or exceeding thresholds for the farm field. The next service consumes inputs for crop, planting date, yield, and fertilizer kind and rates. It computes credits for timing and splitting fertilizer applications to reduce losses, and applying amounts matching crop needs.

http://csip.engr.colostate.edu:8083/csip-wqm/m/nutappmgtscores/1.0

WQM provides a list of 14 management techniques and 42 conservation practices as choices for prescribing additional treatment towards meeting or exceeding threshold levels. The following two services compute credits for the selected techniques and practices. The service groups results by whether treatments avoid, control, or trap nutrient losses.

http://csip.engr.colostate.edu:8083/csip-wqm/m/nut_tech_scores/1.0
http://csip.engr.colostate.edu:8083/csip-wqm/m/nut_pract_scores/1.0

For pesticide hazard mitigation, the next service returns credits for the level of integrated pest management (IPM) applied to the farm field. WQM provides choices for three levels: basic, intermediate, or advanced.

http://csip.engr.colostate.edu:8083/csip-wqm/m/pesticide_ipm_score/1.0

Similar to nutrient loss mitigation, WQM provides a list of 9 management techniques and 39 conservation practices as choices for prescribing additional treatment towards meeting or exceeding threshold levels. The following two services compute credits for the selected techniques and practices.

http://csip.engr.colostate.edu:8083/csip-wqm/m/pest_techn_scores/1.0
http://csip.engr.colostate.edu:8083/csip-wqm/m/pesticide_practice_score/1.0

Finally, WQM provides a simple service to sum and return all treatment credits, as well as threshold levels, for each nutrient loss potential and pesticide hazard category.

http://csip.engr.colostate.edu:8083/csip-wqm/m/wqmscorebar/1.0

The WQM workflow ends with data for scorebars or some other rendering displaying progress of treatment towards meeting or exceeding threshold levels for mitigating nitrogen, phosphorus, and sediment losses, and pesticide hazard to humans and fish

4.0 Discussion

Initial WQM development spanned 7 months, iterating with NRCS subject matter experts during design, coding, and testing, incorporating modifications to specifications as development progressed. Then the nutrient loss potential and pesticide loss potential and hazard rating services were combined into the two services wqmnutrientslpsrp and rs_pest_hazrating described in the previous section. The two services were deployed and integrated with the NRCS Resource Stewardship (RS) application in late 2015. Services, data, and documentation deployed to NRCS are included in a Conservation Resources (CR) release package. WQM services and domain data for RS represented the first CR release, and they remain supported through several subsequent releases containing updates to data and service functionality, currently CR version 2.10. For example, the water table logic was modified in the service code querying the NRCS Soil Data Mart, and additional filters were added to flag invalid

soil components, resolving issues that emerged from field use. NRCS county offices use RS for rapid assessments working with farmers and ranchers.

WQM was designed to support multiple applications, not only within NRCS, but applications of other organizations and initiatives engaged with natural resource assessment on agricultural lands. At least one agricultural sustainability program intends to use WQM services for their water quality metric in the coming months.

Source code for WQM services is open source and can be accessed through the CSIP site at https://alm.engr.colostate.edu/cb/project/csip . Those interested can exercise the services using a tool such as Postman: https://www.getpostman.com .

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