Technical Memorandum

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Subject: Forestry Estimator for Runoff and Nutrients (FERN)

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1. Purpose

The Forestry Estimator for Runoff and Nutrients (FERN) calculator was created for the purpose of estimating water quality benefits from implemented forestry management and forest best management practices (BMPs) (i.e. Forest Stand Improvement). This does not include BMPs directly related to timber harvest. FERN is intended to be a statewide tool to be used by local government units for **planning-level decision making** and calculating water quality benefits for Clean Water Land and Legacy Amendment funding or similar reporting requirements. There is a general lack of models, tools, or estimators for calculating reasonable sediment, phosphorus, and nitrogen load reductions at receiving waterbodies from BMPs implemented within forested lands. FERN can offer an option to fill that space.

1.1. Structure

FERN was created within Microsoft Excel. To calculate sediment, phosphorus, and nitrogen loads and BMP-driven load reductions, static datasets of landscape sediment and nutrient yields, and BMP reduction efficiencies are referenced based on user-selected options that define spatial and physical characteristics of the managed forest area.

2. Calculating existing loads

Existing loads of sediment, total phosphorus, and total nitrogen calculated within FERN are based on data from the United States Geological Survey (USGS) Spatially Referenced Regressions on Watershed attributes (SPARROW) model for the Midwest United States (Robertson and Saad, 2019). The overall SPARROW model is composed of several sub-models for calculating the individual water quality parameters. Within the data from each sub-model, the modeled loads of the parameter are divided into fractional contributions from various sources. Table 1 shows the fractional components of the total loads from the SPARROW model that are used in FERN for estimating existing loads of each water quality parameter.

Table 1. SPARROW model component loads for each water quality parameter. Highlighted components were used for estimating loads from natural/forested land.

Suspended Sediment	
il_ss	Incremental suspended-sediment load, MT/yr
il_ss_uamc	Incremental suspended-sediment load from areas of urban land and medium/course surficial geology, MT/yr
il_ss_ucrc	Incremental suspended-sediment load from areas of urban land and colluvium/residuum/carbonate surficial geology, MT/yr
il_ss_ufs	Incremental suspended-sediment load from areas of urban land and fine/silt surficial geology, MT/yr

Suspended Sediment	
il_ss_aamc	Incremental suspended-sediment load from areas of agricultural land and medium/course surficial geology, MT/yr
il_ss_acrc	Incremental suspended-sediment load from areas of agricultural land and colluvium/residuum/carbonate surficial geology, MT/yr
il_ss_afs	Incremental suspended-sediment load from areas of agricultural land and fine/silt surficial geology, MT/yr
il_ss_oamc	Incremental suspended-sediment load from areas of "other" landuse and medium/course surficial geology, MT/yr
il_ss_ocrc	Incremental suspended-sediment load from areas of "other" landuse and colluvium/residuum/carbonate surficial geology, MT/yr
il_ss_ofs	Incremental suspended-sediment load from areas of "other" landuse and fine/silt surficial geology, MT/yr
il_ss_uaoo	Incremental suspended-sediment load from areas of urban, agricultural and "other" landuses and "other" surficial geology, MT/yr
il_ss_can	Incremental suspended-sediment load from Canada area, MT/yr
il_ss_chan	Incremental suspended-sediment load from channel sources, MT/yr
Total Phosphorus	
il_tp	Incremental total phosphorus load, kg/yr
il_tp_wwtp	Incremental total phosphorus load from wastewater treatment discharge, kg/yr
il_tp_fert	Incremental total phosphorus load from farm fertilizer, kg/yr
il_tp_man	Incremental total phosphorus load from manure, kg/yr
il_tp_geo	Incremental total phosphorus load from natural sources, kg/yr
il_tp_urb	Incremental total phosphorus load from urban land, kg/yr
il_tp_can	Incremental total phosphorus load from Canada, kg/yr
Total Nitrogen	
il_tn	Incremental total nitrogen load, kg/yr
il_tn_wwtp	Incremental total nitrogen load from wastewater treatment discharge, kg/yr
il_tn_fert	Incremental total nitrogen load from farm fertilizer, kg/yr
il_tn_man	Incremental total nitrogen load from manure, kg/yr
il_tn_atm	Incremental total nitrogen load from atmospheric deposition, kg/yr
il_tn_urb	Incremental total nitrogen load from urban land, kg/yr
il_tn_nfix	Incremental total nitrogen load from nitrogen fixing crops, kg/yr
il_tn_can	Incremental total nitrogen load from Canada, kg/yr

SPARROW catchment load data was spatially aggregated up to the USGS hydrologic unit code 12 (HUC 12) sub-watershed scale, and also separately to the county scale for all sub-watersheds and counties in Minnesota. The total loads calculated for each HUC 12, and each county, were then individually converted to yield values (mass/acre). These yield values are then used to estimate the existing total load of sediment, total phosphorus, and total nitrogen from the area of interest within FERN.

2.1. Load modifiers

The calculated existing loads of sediment, total phosphorus, and total nitrogen within FERN are able to be modified using a number of selectable factors. Underlying SPARROW data were spatially aggregated up to the HUC12 subwatershed-scale (or County-scale) to ensure ease of use. However, this led to a generalized loading rate for the entire selected HUC12 watershed or county. Load modifiers allow users to adjust the generalized SPARROW loading rate based on site specific factors (slope, soil type, and forest type) that affect the more localized loads.

2.1.1. Slope

Runoff coefficient values from the Minnesota Stormwater Manual (McCuen, 2017) were used to modify the existing calculated loads based on the slope of the area of interest. The average runoff coefficient for all soil types (A-D) within a slope class (0-2%, 2-6%, >6%) was calculated. The percent difference between the average runoff coefficient of the 0-2% slope class and the >6% slope class was calculated. With the 2-6% slope class assumed to be the 'typical' conditions, the multiplier for the slopes between 0-2% was set at one minus half of the percent difference (as a decimal). The multiplier for the slopes >6% was set at one plus half of the percent difference (as a decimal).

2.1.2. Hydrologic Soil Group

Runoff coefficient values from the Minnesota Stormwater Manual (McCuen, 2017) were also used to modify the existing calculated loads based on the soil type within the area of interest. The average runoff coefficient for all slope classes (0-2%, 2-6%, >6%) within a soil type (A, B, C, or D) was calculated. The percent difference between the average runoff coefficient of A type soil and D type soil was calculated. The multiplier for soil type A was set at one minus half of the percent difference (as a decimal). The multiplier for soil type D was set at one plus half of the percent difference (as a decimal). Separately, the percent difference between the average runoff coefficient of B type soil and C type soil was calculated. The multiplier for soil type B was set at one minus half of that percent difference (as a decimal). The multiplier for soil type C was set at one plus half of that percent difference (as a decimal).

2.1.3. Forest Type

Load of sediment, total phosphorus, and total nitrogen can also be adjusted based on general forest type. Literature values of sediment yield from pine, oak, and mixed forests were used to create loading multipliers to modify the existing calculated loads, with pine representing coniferous forest and oak representing deciduous forest (David et al., 2025). The median value of measured yields from an individual forest type was used to represent the 'typical' sediment yield from that forest type. Load multipliers were created by calculating the percent change between the typical yield for a forest type and the average of typical values for all three forest types.

2.1.4. Overland and channelized decay

Of the total mass of sediment, total phosphorus, and total nitrogen that is generated within the area of interest, a fraction of that mass is redeposited or prevented from being transported downstream due to physical, chemical, or biological factors. Users of FERN have the option to provide a water travel distance between the area of BMP implementation and a downstream waterbody. If the user chooses to supply a travel distance, the 'decay' of the original mass is modeled with first order decay equations. Sediment decay is modeled with the following equation.

$$D = e\text{\^{}}(-\beta T\sqrt{d50})$$

Where D is the delivery fraction, β is the transport coefficient, T is the travel time in hours between the point of origin and the downstream location, and d50 is the median sediment particle diameter in millimeters. The transport coefficient (β) was assumed to be 0.2 and the median sediment diameter (d50) is assumed to be 0.1 mm (BWSR, 2016) based on typical conditions within Minnesota.

Distance traveled as overland flow (within the area of interest - acreage supplied by the user) was assumed to be equal to half of the length of one edge of the area of interest, assuming the area of interest is a square. Travel velocity was assumed to be 0.027 m/s across soil types A-D and 0.023 m/s over peat (Monger et. al, 2022). Distance measurements in combination with velocity were used to estimate total water travel time, which was the primary input for the decay equations.

Nutrient decay is estimated using the following equation

$$W = e^{(-k(T/24))}$$

Where W is the delivery fraction, k is the decay rate, and T is the travel time in hours between the point of origin and the downstream location. The decay rate (k) was assumed to be 0.1 for overland flow within the area of interest, and 0.4 from the outlet of the area of interest to the downstream location (BWSR, 2016).

3. Load reduction

Once the final existing sediment and nutrient load values are calculated, the expected load reduction from an implemented BMP is calculated based on the assumed load reduction efficiency of a selected BMP and the area across which that BMP is being applied.

A number of different sources were used to create a table of sediment, total phosphorus, and total nitrogen load reduction efficiencies (Table 2). Load reduction efficiencies from the NRCS conservation practices physical effects (CPPE) scores are shown in Table 3 (USDA NRCS, 2025).

Table 2. BMP load reduction efficiencies and data source

BMP type	Sediment reduction efficiency (%)	Data source ID	Phosphorus reduction efficiency (%)	Data source ID	Nitrogen reduction efficiency (%)	Data source ID
Brush Management (314)	71	1	0	2	0	2
Herbaceous Weed Treatment (315)	60	3	60	3	50	3
Prescribed Burning (338)	5	2	10	2	10	2
Critical Area Planting (342)	100	4	100	4	100	4
Multi-Story Cropping (379)	50	2	5	2	5	2
Woody Residue Treatment (384)	60	3	60	3	50	3
Firebreak (394)	-5	2	0	2	0	2
Wildlife Habitat Planting (420)	71	1	5	2	5	2
Mulching (484)	71	1	10	2	10	2
Tree/Shrub Site Preparation (490)	83	5	0	2	0	2
Tree/Shrub Establishment (612)	50	5	5	2	5	2
Upland Wildlife Habitat Mgmt (645)	10	2	0	2	0	2
Early Successional Habitat Development/Management (647)	0	2	0	2	0	2
Structures for Wildlife (649)	0	2	0	2	0	2
Forest Trails and Landings (655)	60	3	60	3	50	3
Forest Stand Improvement (666)	71	1	5	2	5	2
Forest Erosion Control	75	6	0	6	0	6
Forest Riparian Management Zones	70	6	70	6	70	6

Data Source ID 1 – Arnold et al., (2012)
Data Source ID 3 – Chesapeake Bay Program, (2024)
Data Source ID 5 – US EPA, (2022)
Data Source ID 2 – USDA NRCS, 2025
Data Source ID 4 – BWSR, (2016)
Data Source ID 6 – MPCA, (2020)

Table 3. NRCS conservation practices physical effects (CPPE) score to load reduction efficiency.

CPPE classification	Assumed BMP efficiency (%)
5 Substantial Improvement	75
4 Moderate to Substantial Improvement	50
3 Moderate Improvement	25
2 Slight to Moderate Improvement	10
1 Slight Improvement	5
0 No Effect	0
-1 Slight Worsening	-5
-2 Slight to Moderate Worsening	-10
-3 Moderate Worsening	-25
-4 Moderate to Substantial Worsening	-50
-5 Substantial Worsening	-75

According to the NRCS CPPE description of classifications:

"*Effect: The magnitude of the practice's effect on the resource concern assuming the practice is fully functional. WORSENING indicates the concern becomes greater and IMPROVEMENT denotes the concern diminishes. The term SLIGHT signifies a noticeable but limited worsening or improvement in the resource concern commensurate with the potential influence at the site level (e.g., generally no more than a 10 percent change in measurable quantities achievable at the site level). The term MODERATE describes a condition more than SLIGHT and less than SUBSTANTIAL. The term SUBSTANTIAL denotes that the practice clearly and markedly worsens or improves the resource concern (e.g., usually more than a 50 percent change at the site level). A rating of No Effect indicates that the fully-functioning practice normally causes no change, a negligible change, or a "net" no effect in the resource concern. No Effect can also be used when the practice normally has no relation to the resource concern.*"

Just as the measurable load of sediment and nutrients diminishes as water moves further from the area of generation, so does the measurable load reduction benefit of an implemented BMP. The measurable load reduction benefit decreases proportionally to the decay of the measurable load. Users who want to know the most localized loading and load reduction estimates can choose to set the 'Approximate distance from managed area or BMP to receiving waterbody (miles)' option in FERN to zero.

4. Assumptions and limitations

All load and load reduction estimates from FERN are calculated at an annual timescale. Storm event-based calculations are not currently calculated. However, the annual estimates of load and load reduction do account for large storm events as the underlying data is derived from long-term monitoring and modeling (Robertson and Saad, 2019).

There was generally a lack of published research on the water quality benefits of forest management BMPs. Values for BMP efficiency were largely taken from existing water quality models or from Natural Resources Conservation Service (NRCS) generalized conservation practices physical effects scores.

Adjustments to existing sediment, phosphorus, and nitrogen loads based on the selected soil type, slope, and/or forest type are calculated primarily based on changes in runoff coefficient due to the selected landscape characteristic. This assumes a linear response between runoff and each selectable parameter, and also a linear response among selectable parameters. There could be dampening or intensifying effects on loads when different combinations of the selected parameters are chosen.

FERN does not account for current or existing BMPs or related conservation efforts within the area of interest and it can only provide load reduction estimates for a single BMP.

The calculator also does not separate nitrogen or phosphorus calculations into the different common species. Only total phosphorus and total nitrogen calculations are available.

5. Future improvements

Although outside of the initial project scope, several future improvements and/or additions to FERN have been discussed. Revisions to the existing calculator can be made in the future as additional data and resources become available.

For instance, additional options could be added to the ‘average slope of managed area’ dropdown if additional research articles are found with more refined data. Expected cost for addition: $3,000-$5,000

Improvements can be made for the estimation of existing loads. Currently the base loading information that is taken from the SPARROW model is modified using linear multipliers that are applied evenly to sediment, phosphorus, and nitrogen loads. Significant improvements can be made to these multipliers including differentiating between effects for each individual water quality parameter, determining if there are compounding effects among the physical landscape parameters, etc. Expected cost for addition: $3,000-$5,000

Although there was very little literature providing information about the water quality benefits of forest-based management, there was a considerable number of resources with information about runoff flow and volume. A future hydrology component can be added to FERN using the same general data format and user interface structure. Expected cost for addition: $6,000-$8,000

Finally, an additional option for selectable canopy cover percentage and/or forest stand age could be added to FERN to further refine existing loads and load reduction potential of the BMPs. Expected cost for addition: $3,000-$5,000

6. References

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