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The DHSVM Rpc Parameter

Origin, Explanation, and Customary Misspecification of a Light-Level ET Parameter

I. Abstract

This paper addresses the little-discussed Rpc parameter that is required in the vegetation section of the configuration file for the Distributed Hydrology Soil Vegetation Model (DHSVM). This parameter is commonly specified as 0.108 in the DHSVM literature, but the source of this value is obscure, and the original DHSVM paper (Wigmosta et al. 1994) references a value of 30 W/m^2 for forest overstory. Here, I provide a chronological exploration of how the 0.108 value originated from a remote sensing survey, followed by an investigation of the source code and the origin of the Rpc equation. I conclude by presenting the results of a sensitivity test of the Rpc parameter in DHSVM for a montane watershed in the Sierra Nevada, which shows as much as a 20% increase in bulk runoff during drought years when using the original literature values in place of 0.108.

II. Origin of the 0.108 Rpc Value

The first known appearance of the value of 0.108 as a DHSVM parameter is in Storck et al. (1995), where it is given in Table 4.2 as the “overstory light level.” The authors state that this table, which includes all of their overstory parameters, “was compiled from a large number of sources,” citing 7 papers, including Peterson et al. (1987), which is the only cited paper to include information about the spectral interaction of solar radiation with photosynthetically active vegetation.

Peterson et al. (1987) measured spectral properties of coniferous forests with the Airborne Thematic Mapper and cited Running (1984) as motivation for investigating the connection of LAI to the absorption of photosynthetically active radiation. The main finding of Peterson et al. (1987) was that the ratio of Near-IR/Red radiance is a good predictor of LAI, which “is explained by a strong asymptotic inverse relationship between LAI and red radiation and a relatively flat response between LAI and near infrared radiation.” Table 1 of Peterson et al. (1987) gives values for the ratio of Near-IR/Red spectral bands for raw and atmospherically corrected measurements across different vegetation zones. The atmospherically corrected Near-IR/Red ratio for “mid-elevation west Cascades, Zone 4” with Western hemlock, Douglas fir, Pacific silver fir, and noble fir dominant species is given as 9.260, as seen in Figure 1 here.

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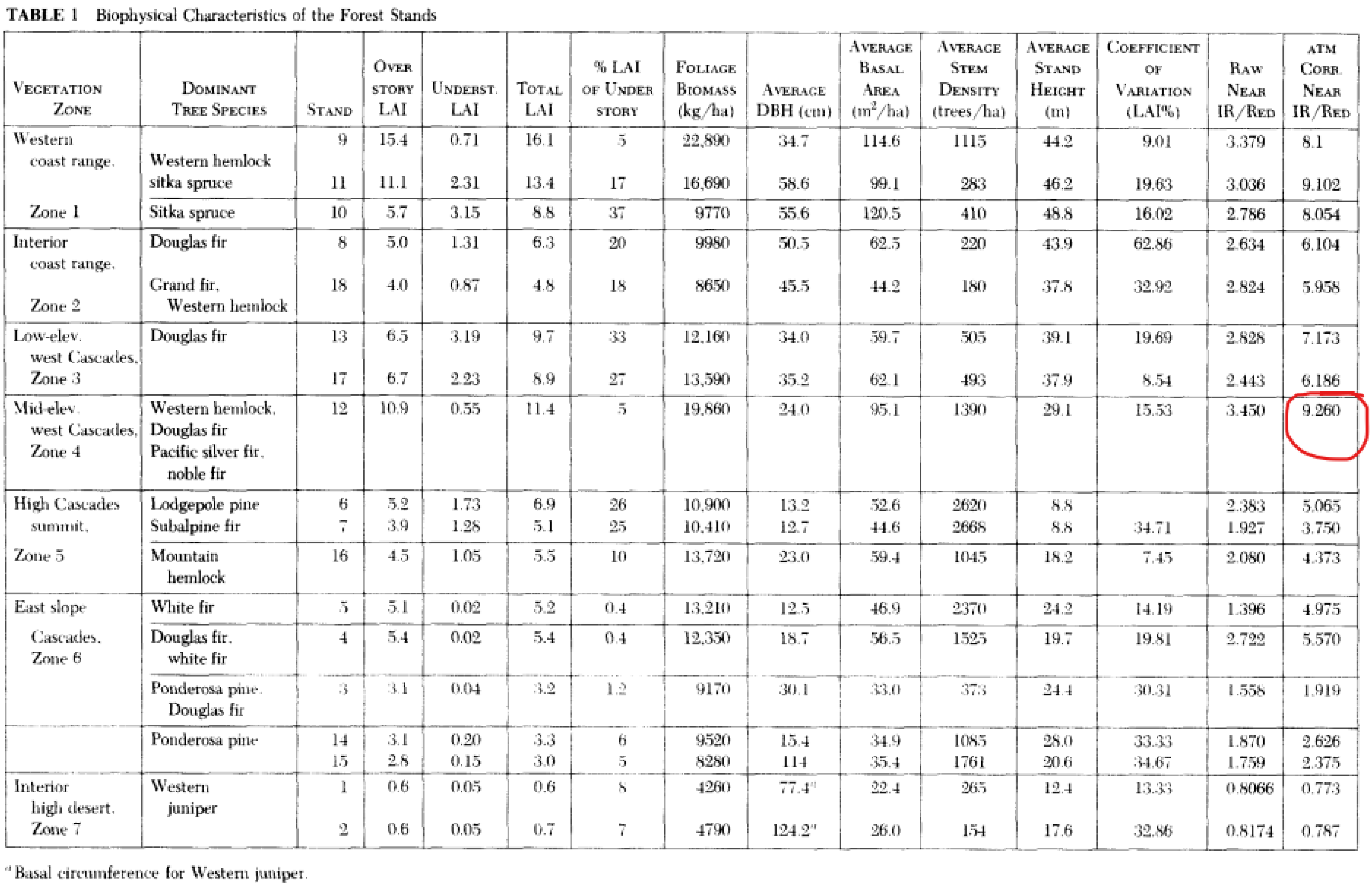

TABLE 1 Biophysical Characteristics of the Forest Stands

Vegetation Zone	Dominant Tree Species	Stand	Over story LAI	Underst. LAI	Total LAI	% LAI of Under story	Foliage Biomass (kg/ha)	Average DBH (cm)	Average Basal Area (m²/ha)	Average Stem Density (trees/ha)	Average Stand Height (m)	Coefficient of Variation (LAI%)	Raw Near IR/Red	atm Corr. Near IR/Red
Western coast range, Zone 1	Western hemlock sitka spruce	9	15.4	0.71	16.1	5	22,890	34.7	114.6	1115	44.2	9.01	3.379	8.1
		11	11.1	2.31	13.4	17	16,690	58.6	99.1	283	46.2	19.63	3.036	9.102
	Sitka spruce	10	5.7	3.15	8.8	37	9770	55.6	120.5	410	48.8	16.02	2.786	8.054
Interior coast range, Zone 2	Douglas fir	8	5.0	1.31	6.3	20	9980	50.5	62.5	220	43.9	62.86	2.634	6.104
	Grand fir, Western hemlock	18	4.0	0.87	4.8	18	8650	45.5	44.2	180	37.8	32.92	2.824	5.958
Low-elev. west Cascades, Zone 3	Douglas fir	13	6.5	3.19	9.7	33	12,160	34.0	59.7	505	39.1	19.69	2.828	7.173
		17	6.7	2.23	8.9	27	13,590	35.2	62.1	493	37.9	8.54	2.443	6.186
Mid-elev. west Cascades, Zone 4	Western hemlock, Douglas fir Pacific silver fir, noble fir	12	10.9	0.55	11.4	5	19,860	24.0	95.1	1390	29.1	15.53	3.450	9.260
High Cascades summit, Zone 5	Lodgepole pine	6	5.2	1.73	6.9	26	10,900	13.2	52.6	2620	8.8		2.383	5.065
	Subalpine fir	7	3.9	1.28	5.1	25	10,410	12.7	44.6	2668	8.8	34.71	1.927	3.750
	Mountain hemlock	16	4.5	1.05	5.5	10	13,720	23.0	59.4	1045	18.2	7.45	2.080	4.373
East slope Cascades, Zone 6	White fir	5	5.1	0.02	5.2	0.4	13,210	12.5	46.9	2370	24.2	14.19	1.396	4.975
	Douglas fir, white fir	4	5.4	0.02	5.4	0.4	12,350	18.7	56.5	1525	19.7	19.81	2.722	5.570
	Ponderosa pine, Douglas fir	3	3.1	0.04	3.2	1.2	9170	30.1	33.0	373	24.4	30.31	1.558	1.919
	Ponderosa pine	14	3.1	0.20	3.3	6	9520	15.4	34.9	1085	28.0	33.33	1.870	2.626
		15	2.8	0.15	3.0	5	8280	114	35.4	1761	20.6	34.67	1.759	2.375
Interior high desert, Zone 7	Western juniper	1	0.6	0.05	0.6	8	4260	77.4[a]	22.4	265	12.4	13.33	0.8066	0.773
		2	0.6	0.05	0.7	7	4790	124.2[a]	26.0	154	17.6	32.86	0.8174	0.787

[a] Basal circumference for Western juniper.

Figure 1. Screenshot of results table from Peterson et al. (1987). The value of atmospherically corrected Near IR/Red reflectance is given as 9.260 for conifer forests of the western Cascades.

Note that 1 / 9.260 = 0.10799 ≈ 0.108, which would be the ratio of red reflectance (mostly absorbed) to Near-IR reflectance (mostly reflected). In their major report on using DHSVM to study the implications of forest roads for flooding in the western Cascades, Storck et al. (1995) list their vegetation parameters in Table 4.2 as mentioned earlier, which indicates that the "overstory light level" for each vegetation category is equal to 0.108, equal to the ratio of Red/Near-IR radiation measured by Peterson et al. (1987) for conifer communities in the Storck et al. (1995) study region.

This value may have been interpreted for DHSVM as the fraction of radiation that is photosynthetically active (i.e., absorbed by vegetation). However, the 0.108 value actually represents the ratio of two atmospherically and topographically corrected upwelling radiance bands. Thus, it seems likely that there was a mistake in the interpretation of Peterson et al. (1987) by Storck et al. (1995), who appear to have interpreted the ratio of two reflectance values as the ratio of absorbed to reflected light. Indeed, since the Near-IR absorption of vegetation is near zero, the Red/Near-IR ratio is close to the Red-only reflectance of vegetation, which would be one minus the absorption.

Most importantly, it appears that the functional meaning of the Rpc value was misunderstood, since it is not intended to be a ratio at all, but rather a single radiation value in W/m^2 (cf. Section III). This misunderstanding could have arisen from an unfortunately worded comment in data.h, a DHSVM header file where many variables are defined. On line 582, a comment defines Rpc as follows: "/* fraction of radiaton [sic] that is photosynthetically active (PAR) */." While it is true that Rpc is related to the amount of photosynthetically active radiation, the idea of a "fraction" is erroneous in this source code comment.

Bowling & Lettenmaier (2002) published another seminal paper on the hydrological effects of forest roads using DHSVM. The authors independently estimate LAI, tree height, and canopy cover for this study, but they note that “due to a lack of age and species-specific information, the remaining vegetation parameters were not changed for each vegetation class (Table 5-2). These parameters were taken from Stork [sic] et al. (1995) and are based on literature values consistent with Pacific Northwest conifers.” While Table 5-2 does include most DHSVM vegetation parameters, Rpc is found in Table 5-4, titled “Derived Soil Parameters.” They provide a footnote on Rpc that states “Rpc is the light level where the soil surface resistance to vapor transport, r_s, is equal to two times the minimum soil surface resistance,” and a value of 0.108 is specified for all 3 soil layers. The confusion of Rpc as a soil parameter may have arisen from the syntax of the EvapoTranspiration.c source code, which calculates canopy resistance inside a loop over each soil layer (lines 140-144). However, the soil layer loop iterates over the variable “i,” and Rpc is indexed with the variable “Layer,” which itself is passed to EvapoTranspiration.c by MassEnergyBalanc.c, where it indicates overstory or understory. The loop over soil layers is necessary because ET is calculated for each vegetation layer’s root fraction in each soil layer.

III. Correcting the Rpc Value

The Rpc parameter is set up in the vegetation section of the configuration file using “Rpc <veg class #> XX.” Rpc is read into (*VType)[i].Rpc by InitTables.c as VarStr[rpc], with the rpc index enumerated in settings.h and (*VType)[i].Rpc is declared as a pointer to a float by VEGTABLE in data.h.

At execution, MainDHSVM.c calls MassEnergyBalance.c, passing VEGTABLE (where Rpc is stored). In MassEnergyBalance.c, a comment defines Rp as “radiation flux in visible part of the spectrum (W/m^2),” consistent with the subsequent discussion here (unlike the erroneous comment in data.h). Rp is calculated on line 349 as VISFRACT * LocalRad->NetShort[0], then passed to EvapoTranspiration.c along with VType (VEGTABLE containing Rpc values). Evapotranspiration.c calls CanopyResistance.c, passing VType->Rpc[Layer] where Layer is an iterated index indicating either the overstory or understory (not the soil layer, which is iterated over i in this calculation).

In CanopyResistance.c, on line 73 the resistance is defined as RsMin times a number of multiplicative factors, including RpFactor, which itself is pre-calculated on line 60 as follows:

$$RpFactor = \frac{1}{\dfrac{\dfrac{RsMin}{RsMax} + \dfrac{Rp}{Rpc}}{1 + \dfrac{Rp}{Rpc}}} \tag{1}$$

Equation 1 here is identical to equation 15 of Wigmosta et al. (1994) after rearranging, with f_3 == RpFactor:

$$\frac{1}{f_3} = \frac{\dfrac{r_{s\,min}}{r_{s\,max}} + \dfrac{R_p}{R_{pc}}}{1 + \dfrac{R_p}{R_{pc}}} \tag{2}$$

Here, f_3 is specified (Wigmosta et al. 1994 equation 12) as a multiplicative factor controlling minimum canopy resistance (resistance ~ minimum resistance * f_3). Wigmosta et al. (1994) cites Dickinson et al. (1993) as the source for this equation, where an identical form is given by equation 60a:

$$R_f = \frac{1 + f}{f + \dfrac{r_{s\,min}}{r_{s\,max}}} \tag{3}$$

Here, $f = F_v/F_{vc}$ where F_{vc} is “the visible solar flux for which R_f is about double its minimum value” and F_v is the “flux of visible solar radiation,” both in units of W/m^2 (Dickinson et al. 1993). Indeed, Rpc must be in units of W/m^2 (not a unitless ratio) to cancel the Rp term as shown above, yielding a purely dimensionless number that is a scale factor on minimum resistance.

Dickinson et al. (1993) further gives F_{vc} (identical to Rpc) as 30 W/m^2 for trees and 100 W/m^2 for grasslands/crops, very different from the value of 0.108 [unitless] used in most DHSVM config files. The purpose of the RpFactor (equivalently, f_3 or R_f) is to increase stomatal resistance (decrease ET) when solar radiation is low enough to induce partial stomatal closure. Dickinson et al. (1993) cites Jarvis (1976) and Hinckley et al. (1978) as motivation for the parameterization of the radiation-limited stomatal resistance factor, and additional references given by Dickinson et al. (1993) include field data supporting the estimates of Rpc: Hinckley et al. (1978) Fig. 3 shows woody angiosperm stomatal resistance doubling around 4000 lux (~30 w/m^2) and Denmead & Millar (1976) Fig. 1 shows the stomatal conductance of wheat leaves halving around 100-200 W/m^2 depending on the treatment of outlying high-conductance values.

Finally, Table 1 of Wigmosta et al. (1994) reports the original vegetation parameter values used in DHSVM, where Rpc is given a value of 30 W/m^2, presumably referenced from Dickinson et al. (1993) as outlined above. It is possible that some or all of the early studies using the value of 0.108 were also using an altered version of the source code that used Rpc in some other context, though there are no indications of this currently forthcoming. I suggest that those using DHSVM with the CanopyResistance.c source code described herein adopt an Rpc value in the range given by the original literature citation (Dickinson et al. 1993) for the function where Rpc is used, i.e., approximately 30 W/m^2 for forests and potentially higher for understory.

IV. Sensitivity Tests

Despite being different by 2 orders of magnitude, the effect of using 0.108 instead of 30 W/m^2 is likely to be small in most cases. Figure 2 shows the effect of these two Rpc values on canopy resistance for a typical forest (minimum resistance = 200 s/m) over a range of incoming shortwave radiation from 0-1000 W/m^2, corresponding to a visible radiation flux of 0-500 W/m^2 since DHSVM assumes that the visible fraction is half of the solar flux. Note that Rpc only significantly affects canopy conductance when the radiation flux is low, a time when ET is likely to be suppressed already.

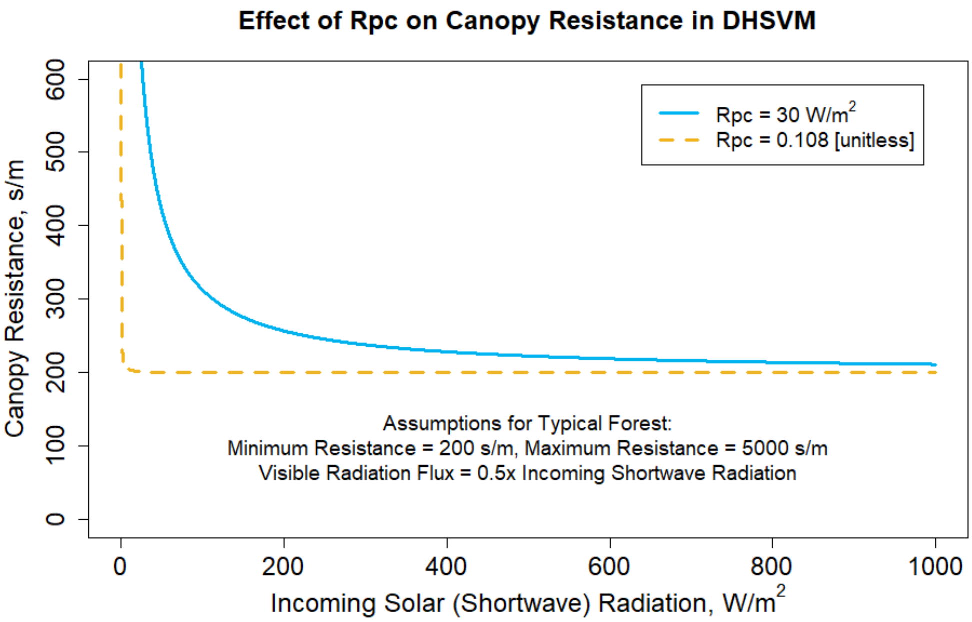

Figure 2. Sensitivity of canopy resistance to the Rpc parameter under varied solar illumination.

Nevertheless, the Rpc parameter can have a significant impact on the water balance of DHSVM. The radiation-scaling factor for canopy resistance (Wigmosta et al. 1994 equation 15) relies on the correct parameterization of Rpc to effectively reduce canopy conductance near dusk and dawn and during cloudy days, including during precipitation events, which can presumably reduce ET during times of moisture abundance. Figures 3 and 4 show the result of a sensitivity test for Rpc carried out by running a 7-year simulation of the Yuba River watershed on a 3-hour timestep using a baseline (uncalibrated) parameterization of DHSVM over water years 2011-2017 (the first year was used for spin-up and was discarded from all plots and analysis). Model runs were completed using a.) Rpc = 0.108 for all vegetation classes, and b.) Rpc = 30 for overstory (forest) and Rpc = 100 for understory (shrub/grass), congruent with Dickinson et al. (1993). Over the 6-year test period, the latter model (higher Rpc) yielded 9% more total runoff than the baseline model with Rpc = 0.108, indicating that Rpc is a nonnegligible control on the catchment water balance, at least in the Mediterranean climate of the western Sierra Nevada.

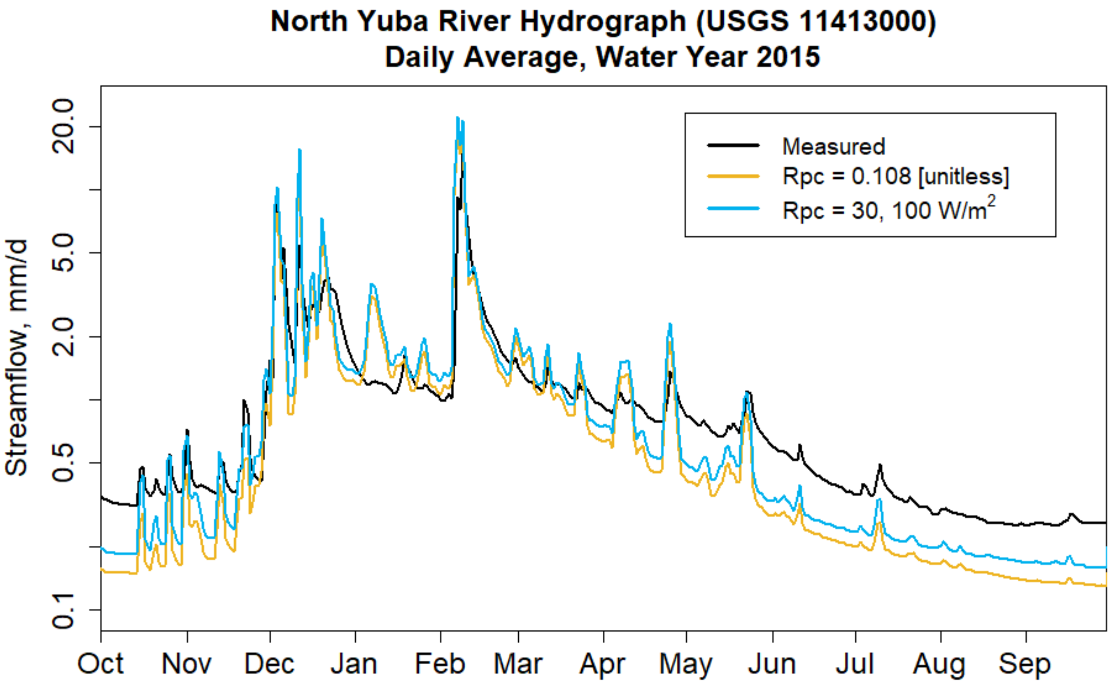

Figure 3. Sensitivity test of the Rpc parameter in DHSVM, daily data. Higher Rpc values (in line with original literature) result in elevated runoff levels by reducing ET during low-light periods.

The sensitivity test shows that the effect of light-induced increases in canopy resistance is most influential during the low-flow regime (Figure 4), where minor changes in upland ET have the greatest proportional effect on the water balance. Both tested models had NSE ≈ 0.78. The relative discrepancy between modeled and measured bulk water yield over this 6-year period indicated 17% underprediction by the model with Rpc = 0.108 and 9% underprediction by the model with overstory Rpc = 30 and understory Rpc = 100.

Direct comparison of the two models indicated that returning the Rpc value to its original range (30 and 100 W/m^2 for overstory and understory, respectively) increased annual runoff. The effect of increasing Rpc on annual runoff varied from an increase of 4% in 2017, a very high moisture year, to as much as 20% in 2014, during a multi-year drought. These results suggest that Rpc could be a heretofore underappreciated control on the water balance of montane catchments modeled in DHSVM, especially during drought conditions.

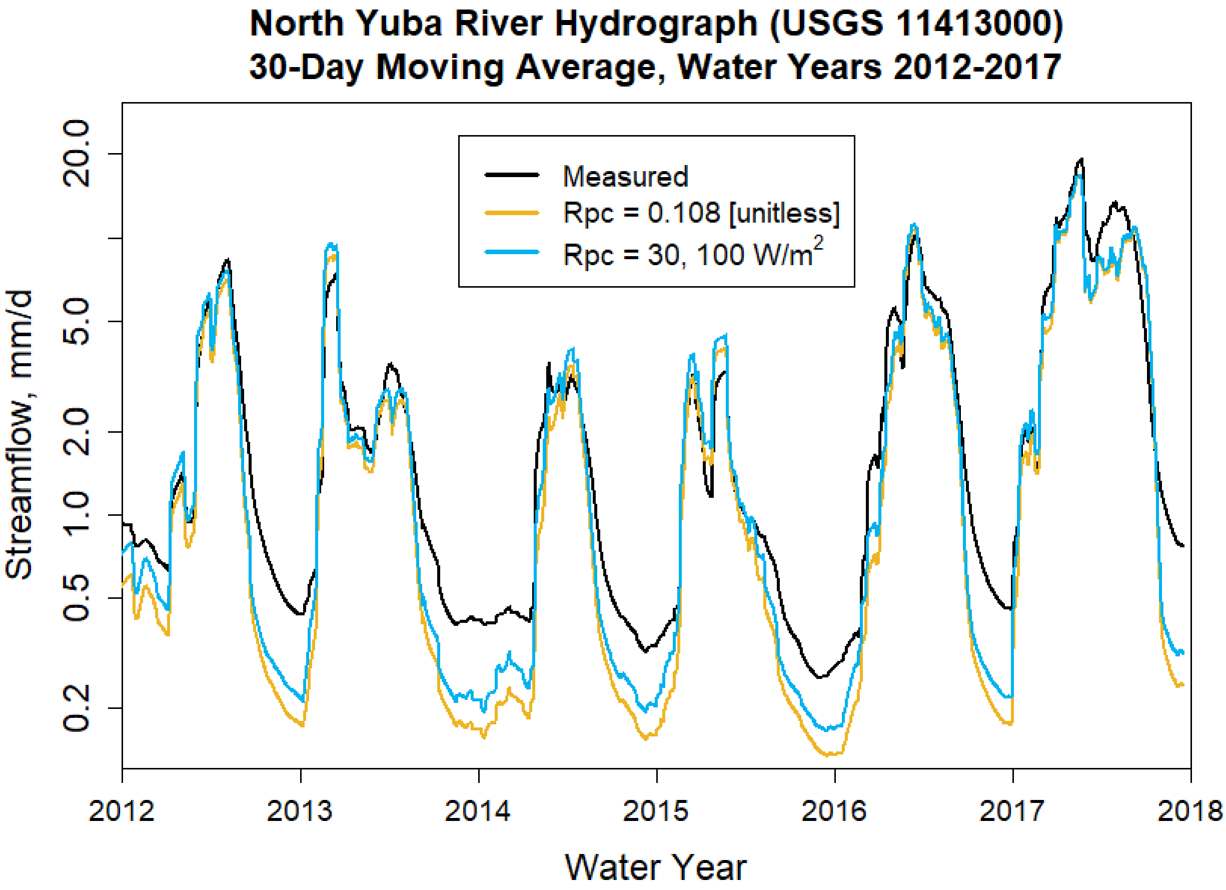

Figure 4. Sensitivity test of the Rpc parameter in DHSVM across multiple years (30-day moving average).

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