USE OF GEOLOGY IN NWSRFS CALIBRATIONS: NISQUALLY RIVER, MT. RAINIER, WASHINGTON

by

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ABSTRACT

Subsurface geology, rock types, and glacial processes greatly influence hydrogeologic processes. Good geologic understanding can create better insights for the initial estimation and subsequent adjustment of parameters of the Sacramento Soil Moisture Accounting (SAC-SMA) and SNOW-17 models of the National Weather Service's River Forecast System (NWSRFS). Geologic information is readily available from the *Roadside Geology* series or US Geological Survey Geologic maps.

The Nisqually River near National, Washington, is divided into four areas in NWSRFS. The Lower area, filled by glaciofluvial sediments, displays a subdued hydrologic response. This geological information translates as deep SAC-SMA tension-water and free-water parameter boxes which indicate high porosity and permeability, plus significant baseflow; low SAC-SMA REXP and ZPERC values suggest rapid percolation; and low SAC-SMA UZK values mean slow recessions. The Middle and Upper areas feature massive volcanic flows which are hydrologically flashy.

The Glacial area shows a glacial peak flow by August. SNOW-17 model parameters show a glacier covering 40% of a volcanic terrain. The NWSRFS Water Balance operation incorporates mass balance analyses (eg., Accumulation Area Ratio) showing glacial growth or recession. The Nisqually glacier shows a 3% decline.

INTRODUCTION

Subsurface and surface geology plus glacial processes strongly controls hydrogeologic processes. Good geologic understanding can create better insights for the initial estimation and subsequent adjustment of parameters of the Sacramento Soil Moisture Accounting (SAC-SMA) and SNOW-17 models of the National Weather Service's River Forecast System (NWSRFS). Geologic information is available from the *Roadside Geology* series, USGS Geologic maps (if finer detail is needed), or specific site studies.

For a conceptual review of the NWSRFS model, refer to Figure 1 (Burnash and Ferral, 1979). The *Upper Zone* refers to surface and interflow/subsurface runoff components. The *Lower Zone* refers to the baseflow/groundwater component. In either zone, the tension water (e.g., *TW*) boxes must be filled before the freewater box (e.g., *FW*) or freewater supplemental (e.g., *FS*) box can fill. Once the FW or FS boxes fill, then water proceeds to percolate to either the lower zone or directly as interflow to a stream. An impervious and direct runoff component also exists. The mechanics of how each zone functions depends on its geologic surroundings, and so a brief review of regional geology, and its implications to NWSRFS, is in order.

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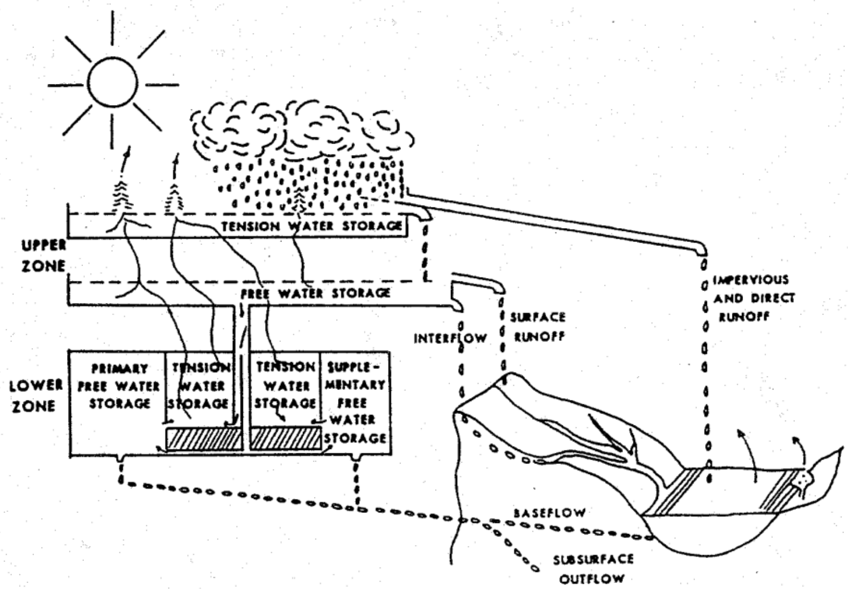

Figure 1.--Illustration of a generalized hydrologic model.

APPLICATIONS OF GEOLOGY

Volcanics

Cascades volcanics are divided into two groups. The Western Cascades are old, solid volcanics that dominate the Washington Cascades (Alt & Hyndman, 1984) and are characterized by:

1. Low porosity, low permeability-- shallow TW and FW boxes.
2. Fast recessions-- relatively high UZK, LZSK (recession).
3. Groundwater recharge-- minimal.
4. *Clay-like* surface-- high REXP, ZPERC (low percolation).
5. Exceptions-- numerous and/or lengthy fractures in columnar basalt can serve as important conduits, leading to the *piping effect* (e.g., flow is proportional to the radius-cubed of the fracture).

The High Cascades are new volcanics (e.g., Mt. St. Helens, McKenzie Pass volcanics) that have *surface* flows with these characteristics:

1. High porosity, high permeability-- deep TW and FW boxes.
2. Slow recessions-- relatively low UZK, LZSK (recession).
3. Groundwater recharge-- significant.
4. *Gravel-like* surface-- low REXP, ZPERC (very high percolation).

Glacial sediments

Late Pleistocene (~10,000 years B.P.) glacial materials exist from British Columbia (B.C.) down past Olympia, Washington and to the foothills of the Washington Cascades and Olympic Mountains.

Glaciofluvial sediments-- well sorted sand and gravel moved by meltwater streams-- display these characteristics:

1. High porosity and permeability-- deep TW and FW boxes. For example, sand is 150 times greater in hydraulic conductivity than that of silt (Rahn, 1986).
2. Slow recessions-- relatively low UZK, LZSK.
3. Groundwater recharge-- significant.
4. *Sand-like* surface-- low REXP, ZPERC.

Glacial till-- poorly sorted jumble of glacial debris-- exhibit:

1. Low porosity and permeability- shallow TW and FW boxes.
2. Slow recessions-- relatively low UZK, LZSK.
3. Groundwater recharge-- variable.
4. Variable surface-- low or high REXP, ZPERC, depending on the amount of cement (usually calcite) in the matrix of the till.

Clay layers-- formed in pro-glacial lakes-- are noted by:

1. No porosity, no permeability-- shallow TW and FW boxes.
2. Fast recessions-- high UZK, LZSK.
3. Groundwater recharge-- none.
4. *Clay-like* surface-- very high REXP, ZPERC.

<u>Glaciology</u>

Pacific Northwest glacial hydrology is a reflection of *warm* mid-latitude glaciers (Sugden & John, 1976), which are characterized by:

1. Surface source-- majority component, seasonal variation.
   a. Snow atop glacier absorbs spring and early summer rain.
   b. Snow melts by July August-- model with SNOW-17 MF VAR (Melt Factor Variation).
   c. Adjacent valley walls absorb and re-radiate heat-- higher melting may occur so use a higher SNOW-17 MFMAX (Melt Factor Maximum).
   d. Surface area of glacier-- model as impervious area with SAC-SMA PCIMP (Percent Impervious area).

2. Basal source-- minority component, continuous flow.
   a. Internal stress/sliding-- produces frictional heat and contributes to melt.
   b. Geothermal heat-- use SNOW-17 DAYGM (Daily Ground Melt). One can use data from papers on geothermal fluxes for specific terrains to compute an exact DAYGM value or use general values (Stacey, 1969).
   c. Temperature of the base of a mid-latitude glacier is <u>above</u> freezing, hence sub-glacial liquid water is readily mobile.

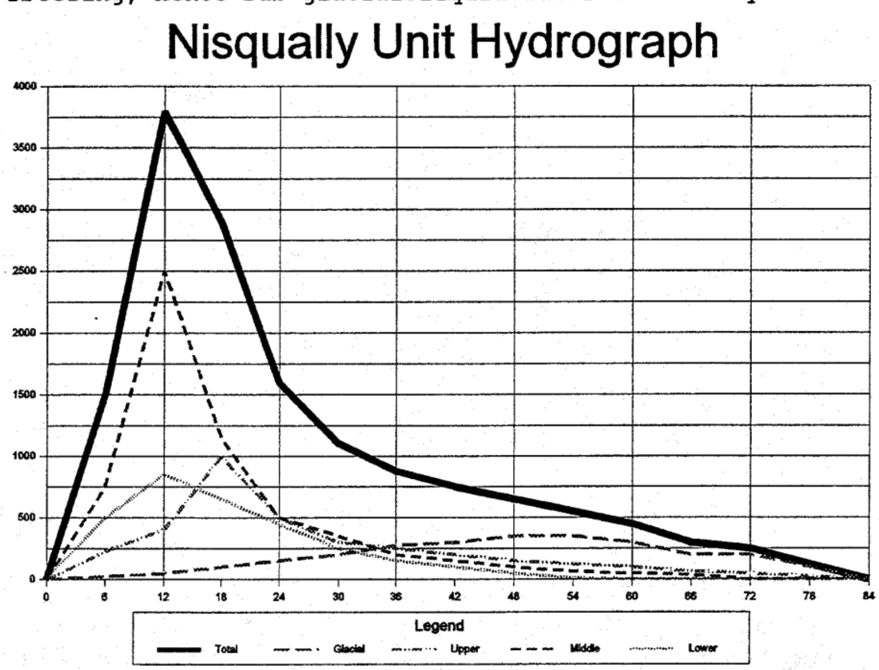

Figure 2.

Glacial unit hydrographs are *flat* a with longer peak time. For example, the average travel time through the Salmon Glacier in B.C. is 39-52 hours. Meltwater channels are well connected by August (Sugden & John, 1976), hence promoting a *rapid* response to a rain event. The Nisqually River unit hydrograph has a glacial component that peaks in 48 hours (Fig. 2).

Glacial budgets depend on the time scales for climatic variations (Porter, 1981). Short, medium, and long-term time scales are superimposed onto one climatic signal. So, how can one tell if a glacier is growing or melting? Long-term glacial growth or melt can be modeled in SNOW-17.

Methods exist to determine glacial mass balance. For example, a *recent* topographic map can be used to find the Accumulation Area Ratio (Porter, 1975, 1981)-- a ratio of accumulation area to total area. AAR values are good for mid-latitude glaciers only and does not specify a *rate* of change of a glacial mass balance. Instructions:

(1) Trace out the glacier on tracing paper.
(2) Determine location of Equilibrium Line (EL), usually the straightest contour across a glacier.
Above the EL is the Accumulation Zone.
(3) Compute the area of the Accumulation Zone. Divide the Accumulation Zone by total area of glacier to compute the AAR.
(4) AAR > 0.65 (*growing*), AAR < 0.65 (melting), or AAR = 0.65 (dynamic equilibrium).

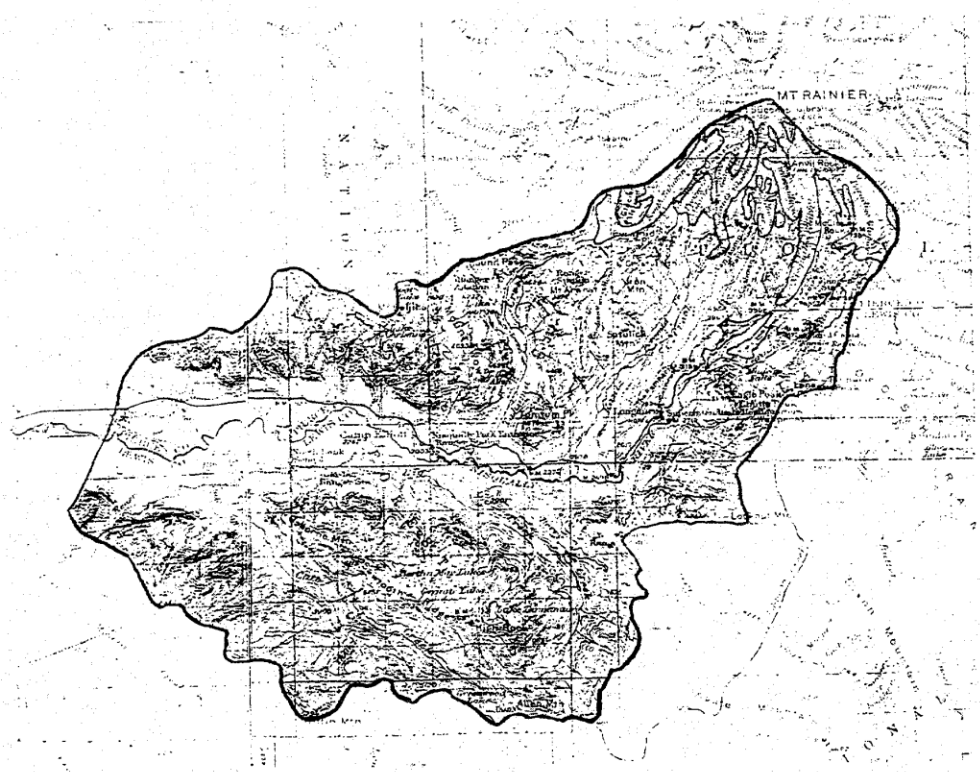

Figure 3. Nisqually River drainage.

NISQUALLY RIVER

The Nisqually River near National, Washington, is divided into four areas in NWSRFS (Figure 3). The Lower area, filled by glaciofluvial sediments, displays a subdued hydrologic response. This geological information translates as deep SAC-SMA TW and FW parameter boxes which suggest high porosity and permeability plus significant baseflow; low SAC-SMA REXP and ZPERC values indicate rapid percolation; and low SAC-SMA UZK values mean slow recessions. The Middle and Upper areas are massive volcanic flows which are hydrologically flashy. For the Glacial area, SNOW-17 and SAC-SMA model parameters show a glacier covering 40% of a solid volcanic terrain. Actually, six glaciers drain into the Nisqually drainage. Overall, the RFS model of Nisqually tracks fairly well (circles are observed data, Figure 4).

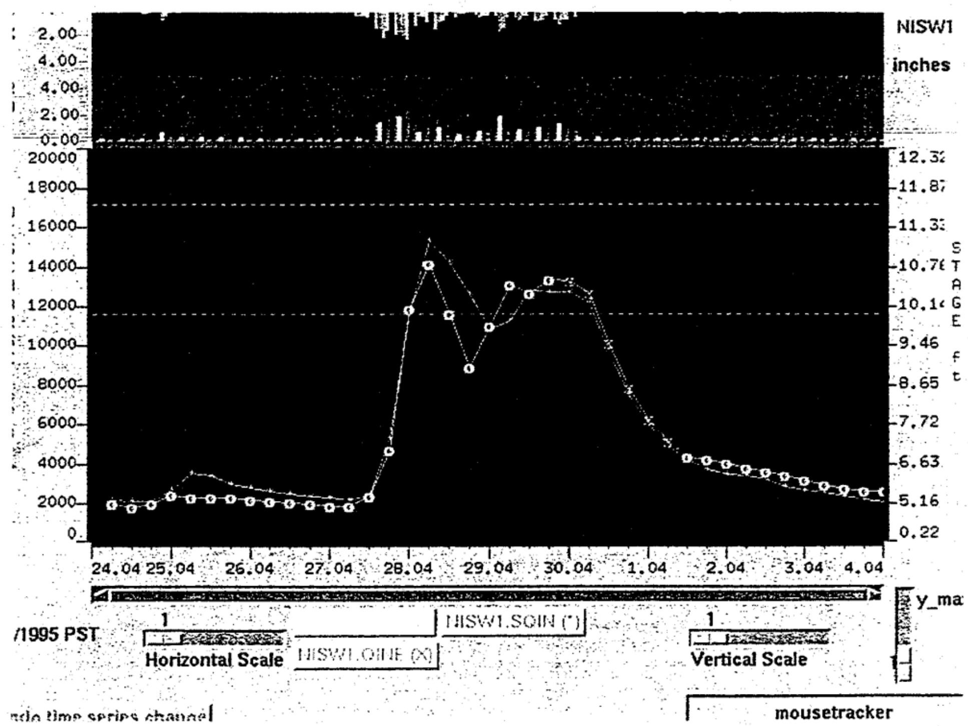

Figure 4. NWSRFS model of Nisqually River near National, November 27-30, 1995

The calibration statistics summary (Table 1) shows a glacial peak flow by August. Glacial melt can be modeled by the SNOW-17 MF VAR curve, which controls the timing of the melt curve, and by SNOW-17 MFMAX and MFMIN (Melt Factor Minimum) which controls the amount of melt.

The first calibration run used default parameters. Geologic reasoning guided subsequent adjustments to model parameters.

For example, on a summary of the NWSRFS calibration parameters for Nisqually (Table 2), note the increasing depth of the SAC-SMA UZTW and LZTW boxes as one moves further downslope into more glacial sedimentary terrains. Percolation rates (e.g., ZPERC and REXP) decrease downslope, until the glacial sedimentary valley floor is reached and rates increase.

The NWSRFS Water Balance operation incorporates mass balance analyses (e.g., Accumulation Area Ratio) showing glacial growth or recession. The Nisqually Glacier has slowly retreated this century, and is reflected as a 3% drop in the mass balance modeled in the NWSRFS Water Balance operation.

SUMMARY

The NWSRFS model is quite conducive for adapting hydrogeologic parameters. The Nisqually River basin can be readily modeled with geologic and glacial processes in mind.

Areas of fresh volcanic surface flows, glaciofluvial sediments, or most sedimentary rocks are hydrologically subdued with high porosity and permeability, slow recessions, and high groundwater recharge. Terrains that are solid volcanics, well cemented sedimentary rocks, clay layers, or metamorphic rocks are hydrologically flashy with low porosity and permeability, fast recessions, and low groundwater recharge. Good geologic understanding of the hydrogeologic processes can enhance and speed up the calibration process for any basin.

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TABLE 1. MULTIYEAR STATISTICAL SUMMARY OF NISQUALLY RIVER NEAR NATIONAL, WASHINGTON

NISQUALLY @ NATIONAL AREA (SQ KM) = 354.50 WATER YEARS 1949 TO 1992

MONTHLY	SIMULATED MEAN (CMSD)	OBSERVED MEAN (CMSD)	PERCENT BIAS	MONTHLY BIAS (SIM-OBS) (MM)	MAXIMUM ERROR (SIM-OBS) (CMSD)	PERCENT AVERAGE ABSOLUTE ERROR	PERCENT DAILY RMS ERROR	MAX MONTHLY VOLUME ERROR (MM)	PERCENT AVG ABS MONTHLY VOL ERROR	PERCENT MONTHLY VOL RMS ERROR
OCTOBER	12.496	13.201	-5.34	-5.329	60.579	32.43	51.66	-113.270	19.49	28.56
NOVEMBER	24.142	23.129	4.38	7.407	-125.496	24.75	46.60	71.333	11.38	14.96
DECEMBER	26.689	27.458	-2.80	-5.809	-240.238	23.92	50.44	-170.944	14.80	21.11
JANUARY	23.717	24.854	-4.58	-8.592	-133.233	24.91	49.39	115.542	14.41	19.64
FEBRUARY	23.248	23.275	-.11	-.182	65.254	22.98	36.84	-71.980	14.65	18.35
MARCH	18.841	18.006	4.64	6.311	-34.749	20.85	30.38	-77.264	14.73	19.68
APRIL	22.022	22.353	-1.48	-2.415	-31.520	17.04	23.51	-48.271	10.32	12.72
MAY	28.609	29.081	-1.62	-3.563	-26.007	14.10	18.59	-65.524	9.77	12.10
JUNE	29.751	30.369	-2.04	-4.519	52.328	17.25	23.62	96.818	13.34	16.36
JULY	23.782	23.329	1.94	3.421	29.501	19.60	25.76	-68.629	15.16	18.51
AUGUST	17.084	16.261	5.06	6.217	38.547	21.65	31.94	75.313	15.90	19.92
SEPTEMBER	13.092	12.501	4.72	4.318	33.291	25.24	39.08	33.382	12.51	15.83
YEAR AVG	21.943	21.974	-.14	-2.735	-240.238	21.32	37.27	-170.944	13.58	18.26

DAILY RMS ERROR (CMSD)	DAILY AVERAGE ABS ERROR (CMSD)	AVERAGE ABS MONTHLY VOL ERROR (MM)	MONTHLY VOLUME RMS ERROR (MM)	CORRELATION COEFFICIENT DAILY FLOWS	LINE OF BEST FIT OBS = A + B*SIM A	B
8.190	4.686	22.136	29.769	.8829	2.7592	.8757

FLOW INTERVAL		NUMBER OF CASES	SIMULATED MEAN (CMSD)	OBSERVED MEAN (CMSD)	PERCENT BIAS	BIAS (SIM-OBS) (MM)	MAXIMUM ERROR (CMSD)	PERCENT AVG ABS ERROR	PERCENT RMS ERROR
.00 -	11.00	2925	8.542	8.653	-1.29	-.0273	26.392	26.54	35.12
11.00 -	14.70	2924	13.808	12.810	7.79	.2432	27.414	24.14	32.85
14.70 -	19.00	2955	17.744	16.784	5.72	.2341	38.547	21.09	29.07
19.00 -	25.30	2935	22.207	21.803	1.85	.0985	72.735	19.35	26.44
25.30 -	40.00	2938	30.306	31.257	-3.04	-.2319	56.319	19.11	25.67
40.00 -	50.50	693	43.294	44.606	-2.94	-.3199	52.984	19.71	25.48
50.50 AND ABOVE		701	72.237	77.091	-6.30	-1.1832	-240.238	24.16	36.42

TABLE 2. SUMMARY OF NWSRFS CALIBRATION PARAMETERS OF NISQUALLY RIVER NEAR NATIONAL, WASHINGTON.

RAIN-SNOW ELEVATION OPERATION--PXTEMP= .5 DEGC LAPSE RATE= .55 DEGC/100 M

SNOW-17 OPERATION NAME=NISW1G
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MAJOR PARAMETERS		SCF	MFMAX	MFMIN	UADJ	SI							
		1.28	.80	.02	.200	0.							
MF VARIATION		1	2	3	4	5	6	7	8	9	10	11	12
		.00	.00	.00	.00	.80	1.00	.90	.50	.40	.10	.00	.00
MINOR PARAMETERS		NMF	TIPM	MBASE	PXTEMP	PLWHC	DAYGM						
		.01	.61	.0	.2	.02	.03						
DEPLETION CURVE	WE/AI	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	
	COVER	0.05	.08	.12	.16	.20	.35	.70	.84	.90	.95	1.0	

RAIN-SNOW ELEVATION OPERATION--PXTEMP= -.2 DEGC LAPSE RATE= .55 DEGC/100 M

SNOW-17 OPERATION NAME=NISW1U
****

MAJOR PARAMETERS		SCF	MFMAX	MFMIN	UADJ	SI						
		1.13	.95	.03	.020	800.						
MINOR PARAMETERS		NMF	TIPM	MBASE	PXTEMP	PLWHC	DAYGM					
		.33	.21	.0	.2	.03	.04					
DEPLETION CURVE	WE/AI	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	COVER	0.05	.08	.12	.16	.20	.35	.70	.84	.90	.95	1.0

RAIN-SNOW ELEVATION OPERATION--PXTEMP= -.3 DEGC LAPSE RATE= .55 DEGC/100 M

SNOW-17 OPERATION NAME=NISW1M
****

MAJOR PARAMETERS		SCF	MFMAX	MFMIN	UADJ	SI						
		1.07	.85	.20	.020	800.						
MINOR PARAMETERS		NMF	TIPM	MBASE	PXTEMP	PLWHC	DAYGM					
		.55	.52	.0	.2	.04	.04					
DEPLETION CURVE	WE/AI	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	COVER	0.05	.08	.12	.16	.20	.35	.70	.84	.90	.95	1.0

RAIN-SNOW ELEVATION OPERATION--PXTEMP= -.4 DEGC LAPSE RATE= .55 DEGC/100 M

SNOW-17 OPERATION NAME=NISW1L
****

MAJOR PARAMETERS		SCF	MFMAX	MFMIN	UADJ	SI						
		1.00	.95	.55	.070	400.						
MINOR PARAMETERS		NMF	TIPM	MBASE	PXTEMP	PLWHC	DAYGM					
		.24	.61	.0	.2	.05	.05					
DEPLETION CURVE	WE/AI	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	COVER	0.05	.30	.45	.60	.70	.76	.82	.87	.92	.97	1.0

TABLE 2. SUMMARY OF NWSRFS CALIBRATION PARAMETERS OF NISQUALLY RIVER NEAR NATIONAL, WASHINGTON.

SAC-SMA OPERATION NAME=NISW1G
****

PX-ADJ	PE-ADJ	UZTWM	UZFWM	UZK	PCTIM	ADIMP	RIVA	EFC	DAILY ET DIST.
1.000	.100	25.	27.	.500	.400	.001	.000	.100	UNIFORM

PBASE	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	RSERV	SIDE
9.6	75.0	2.50	128.	45.	143.	.1500	.0200	.15	.30	.00

16TH OF MONTH VALUES	1	2	3	4	5	6	7	8	9	10	11	12
ET-DEMAND-MM/DAY	.1	.3	1.3	1.8	2.4	3.0	4.1	3.7	2.8	1.0	.8	.1

SAC-SMA OPERATION NAME=NISW1U
****

PX-ADJ	PE-ADJ	UZTWM	UZFWM	UZK	PCTIM	ADIMP	RIVA	EFC	DAILY ET DIST.
1.000	1.000	40.	27.	.400	.020	.000	.000	.960	UNIFORM

PBASE	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	RSERV	SIDE
9.2	50.0	2.20	138.	45.	143.	.1400	.0200	.15	.30	.00

16TH OF MONTH VALUES	1	2	3	4	5	6	7	8	9	10	11	12
ET-DEMAND-MM/DAY	.1	.3	1.3	1.8	2.4	3.0	4.1	3.7	2.8	1.0	.8	.1

SAC-SMA OPERATION NAME=NISW1M
****

PX-ADJ	PE-ADJ	UZTWM	UZFWM	UZK	PCTIM	ADIMP	RIVA	EFC	DAILY ET DIST.
1.000	1.000	50.	27.	.383	.000	.000	.000	.970	UNIFORM

PBASE	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	RSERV	SIDE
5.6	50.0	2.10	158.	35.	143.	.1100	.0120	.15	.30	.00

16TH OF MONTH VALUES	1	2	3	4	5	6	7	8	9	10	11	12
ET-DEMAND-MM/DAY	.1	.3	1.3	1.8	2.4	3.0	4.1	3.7	2.8	1.0	.8	.1

SAC-SMA OPERATION NAME=NISW1L
****

PX-ADJ	PE-ADJ	UZTWM	UZFWM	UZK	PCTIM	ADIMP	RIVA	EFC	DAILY ET DIST.
1.000	1.100	50.	32.	.183	.000	.000	.100	.850	UNIFORM

PBASE	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	RSERV	SIDE
7.4	30.0	1.80	170.	35.	143.	.1500	.0150	.15	.30	.00

16TH OF MONTH VALUES	1	2	3	4	5	6	7	8	9	10	11	12
ET-DEMAND-MM/DAY	.1	.3	1.3	1.8	2.4	3.0	4.1	3.7	2.8	1.0	.8	.1