Appendix K
Model Configuration, Calibration and Validation

Basin: Nebraska: Loup and Elkhorn Rivers (Neb)

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Watershed Background

The Loup and Elkhorn River basins within the Central Nebraska NAWQA study area were selected as one of the 15 non-pilot application watersheds for the 20 Watershed study. Watershed modeling for the non-pilot areas is accomplished using the SWAT model only, and model calibration and validation results are presented in abbreviated form.

Water Body Characteristics

The Loup and Elkhorn River basins are tributary to the Platte River (Huntzinger and Ellis, 1993). Together they include 14 HUC8s within HUC 1021 and 1022 and cover approximately 22,100 mi^2 (Figure 1). The Loup River basin includes the North Loup, Middle Loup, and South Loup Rivers, as well as Calamus River, Cedar River, Dismal River, and Mud Creek. Major tributaries of the Elkhorn River include the North Fork Elkhorn River and Logan Creek.

The watersheds are located in the Central Plains ecoregion (Huntzinger and Ellis, 1993). The Loup River and its major tributaries originate in the Nebraska Sandhills, a region of steep grass-covered dunes, and then flow through dissected plains with broad valleys. Permeable soils and subsurface materials in the Loup River basin provide flows sustained by shallow groundwater and little if any runoff. The Elkhorn River, in the eastern and northeastern part of the watershed, flows through rolling hills and well-defined valleys of stable glacial material in the Western Corn Belt Plains except where it originates in the Sandhills. Runoff in the Elkhorn basin is the largest in the watershed because of the steeper slopes and fine-grained soils. The city of Omaha lies just outside the watershed. The portion of the watershed along the eastern boundary is influenced by the Omaha suburban area and is located near the mouth of the Platte River. Most of the water in the watershed is consumed by irrigation or used for power generation and returned to the stream for reuse. The water used for irrigation is primarily from groundwater. The few urban areas within the watershed use groundwater as a municipal water supply. The city of Omaha obtains part of its water supply from wells in the Elkhorn and Platte River Valleys.

The watersheds are dominated by rural areas. The land use is predominantly pasture and rangeland (66 percent) and croplands of row-cropped feed grains (27 percent). Groundwater development for irrigation has increased the productivity of agriculture in the valleys and uplands. Large areas have soils well suited to cultivated crops whereas other large areas are not suited to crops but to productive grasslands. Counties that are primarily cropland agriculture without urban areas have population densities of 50 persons per square mile or less. Areas in the west that are primarily rangeland have population densities of less than five persons per square mile.

The central Nebraska climate ranges from semiarid in the northwest to subhumid in the east. Hot summers, cold winters, and large daily and annual variations in temperature are typical. Precipitation is greatest in May and June. Mean annual precipitation varies from about 18 inches in the western part of the watershed to about 30 inches in the eastern part. Most of the study unit has at least 20 inches of annual precipitation, and more than one-half occurs during the growing season, April through September. Snowfall is a dominant climatic characteristic of central Nebraska. Mean annual snowfall ranges from about 25 inches in the southeast to about 35 inches in the northwest.

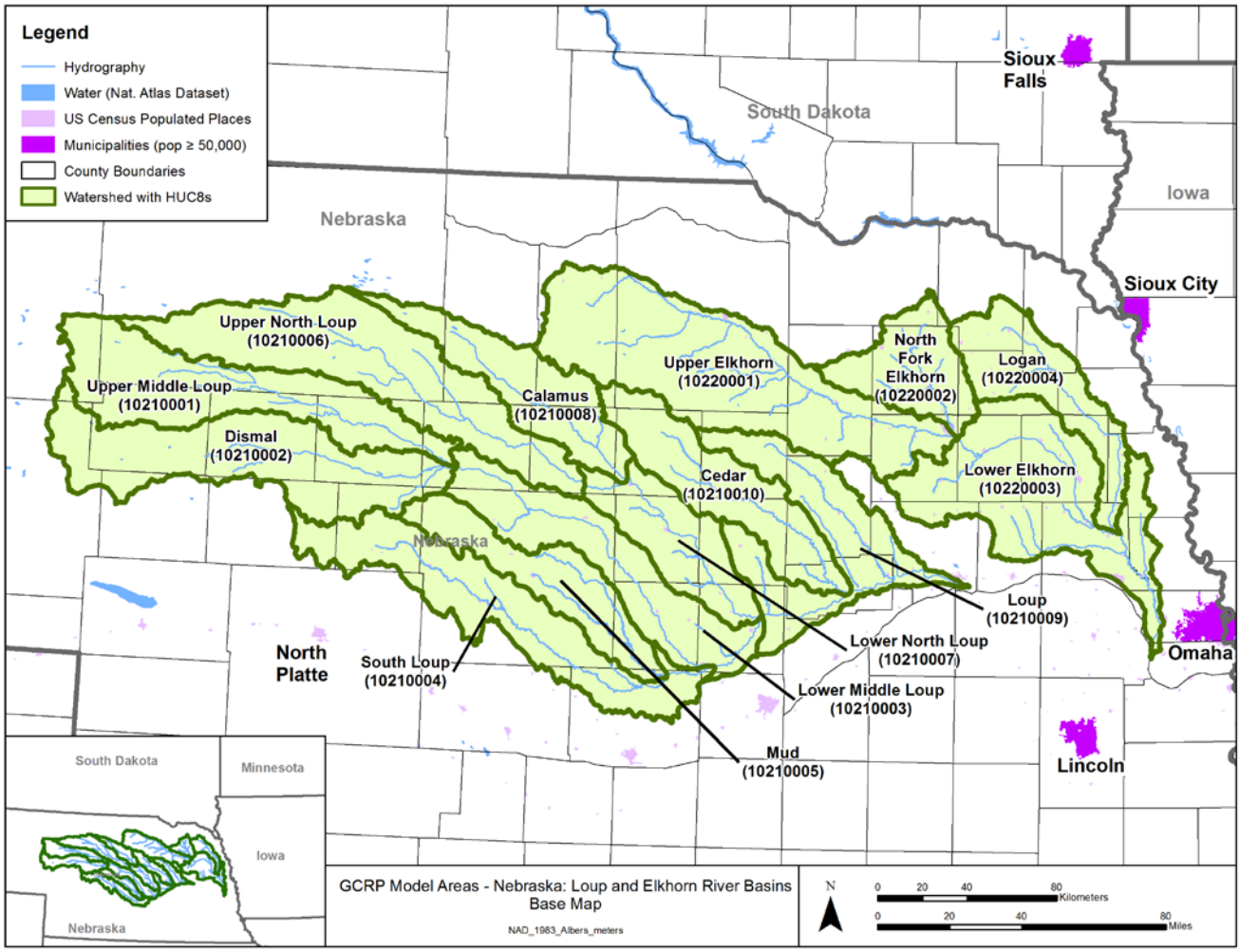

Figure 1. Location of the Loup and Elkhorn River basins

Soil Characteristics

Soils in the watershed, as described in STATSGO soil surveys, fall primarily into hydrologic soil groups (HSGs) A (high infiltration capacity) and B (moderately high infiltration capacity). SWAT uses information drawn directly from the soils data layer to populate the model.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage and is predominantly rangeland in the northwest and row crop agriculture in the south and east (Figure 2). NLCD land cover classes were aggregated according to the scheme shown in Table 1 for representation in the 20 Watershed model. SWAT uses the built-in hydrologic response unit (HRU) overlay mechanism in the ArcSWAT interface. SWAT HRUs are formed from an intersection of land use and SSURGO major soils. The distribution of land use in the watershed is summarized in Table 2.

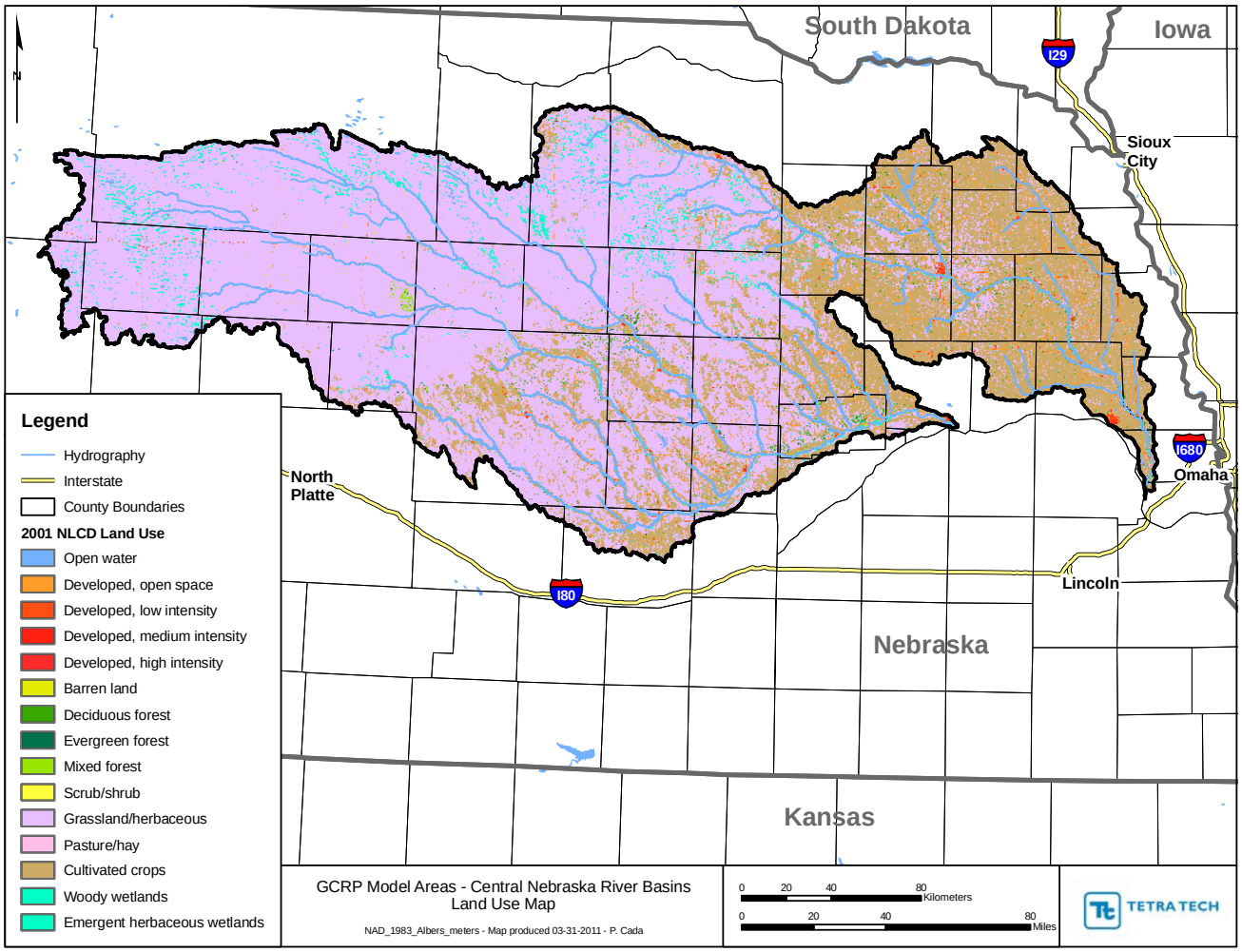

Figure 2. Land use in the Loup and Elkhorn River basins.

Table 1. Aggregation of NLCD land cover classes

NLCD Class	Comments	SWAT class
11 Water	Water surface area usually accounted for as reach area	WATR
12 Perennial ice/snow		WATR
21 Developed open space		URLD
22 Dev. Low Intensity		URMD
23 Dev. Med. Intensity		URHD
24 Dev. High Intensity		UIDU
31 Barren Land		SWRN
41 Forest	Deciduous	FRSD
42 Forest	Evergreen	FRSE
43 Forest	Mixed	FRST
51-52 Shrubland		RNGB
71-74 Herbaceous Upland		RNGE
81 Pasture/Hay		HAY
82 Cultivated		AGRR
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR

Table 2. Land use distribution for the Loup and Elkhorn River basins (2001 NLCD) (mi^2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland/ Grassland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
Upper Elkhorn **10220001**	25.2	71.8	10.9	2.1	1.1	2.6	22.5	1,724.7	129.4	719.9	182.6	**2,892.8**
North Fork Elkhorn **10220002**	2.9	34.6	7.6	1.5	0.8	0.1	17.0	198.0	1.2	580.8	4.2	**848.6**
Lower Elkhorn **10220003**	17.6	86.9	22.2	4.4	1.6	0.2	45.2	311.1	20.4	1,667.5	29.4	**2,206.6**
Logan **10220004**	2.7	40.5	10.1	0.9	0.4	0.0	7.1	111.2	10.9	866.1	3.1	**1,053.1**
Upper Middle Loup **10210001**	25.9	9.0	3.4	0.3	0.1	0.7	4.7	1,955.0	3.3	2.5	85.7	**2,090.6**
Dismal **10210002**	8.8	2.8	0.3	0.0	0.0	1.6	14.8	1,711.6	4.0	6.2	40.3	**1,790.5**
Lower Middle Loup **10210003**	19.6	48.7	9.4	1.1	0.2	1.0	21.7	1,310.2	10.9	347.9	38.7	**1,809.5**
South Loup **10210004**	4.1	42.3	5.5	0.3	0.1	0.8	14.8	1,133.3	10.5	335.1	34.0	**1,580.8**
Mud **10210005**	0.3	26.4	8.1	1.3	0.3	0.3	9.4	488.8	7.0	195.0	3.9	**740.8**
Upper North Loup **10210006**	25.7	10.5	0.9	0.0	0.0	0.9	3.1	2,181.3	3.3	20.4	103.4	**2,349.4**
Lower North Loup **10210007**	9.8	32.1	6.1	0.7	0.2	0.4	31.4	643.8	10.6	224.2	18.5	**977.9**
Calamus **10210008**	22.3	2.7	0.1	0.0	0.0	1.0	1.3	904.9	1.1	7.1	50.7	**991.3**
Loup **10210009**	12.4	51.1	9.9	1.3	0.6	1.6	26.0	678.1	28.6	663.5	60.5	**1,533.7**
Cedar **10210010**	6.5	28.5	3.1	0.2	0.1	1.2	14.7	897.7	9.2	226.2	42.6	**1,229.9**
Total	**183.8**	**488.0**	**97.4**	**14.3**	**5.5**	**12.5**	**233.8**	**14,249.7**	**250.4**	**5,862.5**	**697.4**	**22,095.4**

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (8.34%), low density (29.68%), medium density (60.14%), and high density (86.59%).

Point Sources

There are several point source discharges in the watershed. Only the major dischargers, primarily those with a design flow greater than 1 MGD, are included in the simulation (Table 3). The major dischargers are represented at long-term average flows, without accounting for changes over time or seasonal variations.

Table 3. Major point source discharges in the Loup and Elkhorn River basins

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
NE0000761	TYSON FRESH MEATS INC W POINT	1.3	0.79
NE0001392	TYSON FRESH MEATS, INC.	3.6	3.36
NE0028363	TYSON FRESH MEAT INC. MADISON	1.2	0.56
NE 0031381	FREMONT WWTF	10.5	4.05
NE0033421	NORFOLK WWTF	3.47	3.75
NE0035025	COLUMBUS WWTF	2.6	4.31
NE0111287	NUCOR STEEL NORFOLK	0.118	0.46

Most of these point sources have reasonably good monitoring data available for total suspended solids (TSS), but not for nutrients. The point sources were thus represented in the model with the median of reported values for TSS and nutrient concentrations set to representative values by SIC code (Tetra Tech 1999).

Meteorological Data

The required meteorological time series for the 20 Watershed SWAT simulations are precipitation and air temperature. The 20 Watershed simulations do not include water temperature simulation and use a degree-day method for snowmelt. SWAT estimates Penman-Monteith potential evapotranspiration using a statistical weather generator for inputs other than temperature and precipitation. These meteorological time series are drawn from the BASINS4 Meteorological Database (USEPA 2008), which provides a consistent, quality-assured set of nationwide data with gaps filled and records disaggregated. Scenario application requires simulation over 30 years, so the available stations are those with a common 30-year period of record (or one that can be filled from an approximately co-located station) that includes the year 2001, if possible. A total of 57 precipitation stations were identified for use in the Loup and Elkhorn River basins model with a common period of record of 10/1/1968-12/31/1999 (Table 4). Due to the discontinuance of many stations a simulation period ending slightly prior to 2001 was chosen. Temperature records are sparser; where these are absent temperature is taken from nearby stations with an elevation correction.

Table 4. Precipitation stations for the Loup and Elkhorn River basins model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
NE250070	ALBION	41.6842	-98.0033	X	546
NE250180	AMELIA 2W	42.2347	-98.9506	X	668
NE250245	ANSELMO 2 SE	41.5975	-99.8258	X	794
NE250320	ARCADIA	41.4244	-99.1231		658
NE250355	ARNOLD	41.4242	-100.193		838

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
NE250365	ARTHUR	41.5697	-101.691	X	1067
NE250385	ASHTON	41.2481	-98.7989		620
NE250420	ATKINSON	42.5342	-98.9783	X	643
NE250525	BARTLETT 4S	41.8278	-98.5494		652
NE250680	BEEMER	41.9325	-96.8108		415
NE251130	BREWSTER	41.9375	-99.8628	X	760
NE251200	BROKEN BOW 2 W	41.4083	-99.675	X	762
NE251345	BURWELL	41.7769	-99.1433	X	663
NE251590	CHAMBERS	42.2031	-98.7467	X	649
NE251660	CLARKSON	41.7239	-97.1256	X	472
NE251776	COLERIDGE	42.5056	-97.2086		488
NE251835	COMSTOCK	41.5569	-99.2372		687
NE252380	DODGE	41.7233	-96.8828		427
NE252595	ELGIN	41.9872	-98.0747		590
NE252645	ELLSWORTH	42.0631	-102.283		1190
NE252647	ELLSWORTH 15 NNE	42.2647	-102.214	X	1210
NE252770	ERICSON 6 WNW	41.7986	-98.7842		642
NE252805	EWING	42.2611	-98.3417	X	564
NE253050	FREMONT	41.43	-96.4669	X	360
NE253075	FULLERTON	41.3594	-97.9761		503
NE253185	GENOA 2 W	41.4514	-97.7644	X	485
NE253425	GREELEY	41.5461	-98.5336	X	616
NE253630	HARTINGTON	42.6167	-97.2608	X	418
NE254986	LOUP CITY 6 NNE	41.3611	-98.9222		677
NE255050	LYONS	41.9378	-96.4789		390
NE255080	MADISON 2W	41.8306	-97.49	X	511
NE255250	MASON CITY	41.2231	-99.3008		689
NE255370	MEADOW GROVE	42.0292	-97.7386		497
NE255525	MILLER	40.9283	-99.3886		704
NE255702	MULLEN 21 NW	42.2506	-101.336	X	1055
NE255830	NELIGH	42.1303	-98.0275		536

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
NE255925	NEWPORT	42.6008	-99.3333	X	680
NE256040	NORTH LOUP	41.4933	-98.7747	X	597
NE256135	OAKDALE	42.0678	-97.9675	X	521
NE256167	OCONTO	41.1439	-99.7633	X	786
NE256290	O NEILL	42.4594	-98.6564	X	607
NE256386	OSHKOSH 10 NE	41.5	-102.183	X	327
NE256395	OSMOND	42.3569	-97.5969	X	503
NE256630	PENDER	42.1153	-96.7058		408
NE256720	PIERCE	42.1958	-97.5206		485
NE256735	PILGER	42.0067	-97.0561		429
NE256970	PURDUM	42.065	-100.247	X	820
NE257040	RAVENNA	41.0333	-98.9142	X	625
NE257515	SAINT PAUL 4 N	41.2686	-98.4697	X	541
NE257685	SCRIBNER	41.6678	-96.6689		382
NE258025	SPALDING	41.6031	-98.3483		578
NE258110	STANTON	41.9564	-97.2222	X	469
NE258455	TAYLOR	41.7708	-99.3814		692
NE258480	TEKAMAH	41.7861	-96.2264	X	338
NE259050	WAYNE 4 NW	42.295	-97.0569		457
NE259200	WEST POINT	41.845	-96.7142	X	399
NE259262	WHITMAN 4 E	42.0828	-101.431		1093

Watershed Segmentation

The Loup and Elkhorn River basins was divided into 114 subwatersheds for the purposes of modeling (Figure 3). The initial calibration watershed was selected as Elkhorn River at Waterloo (USGS 06800500). The area modeled encompasses complete watersheds and does not require specification of any upstream boundary conditions for application.

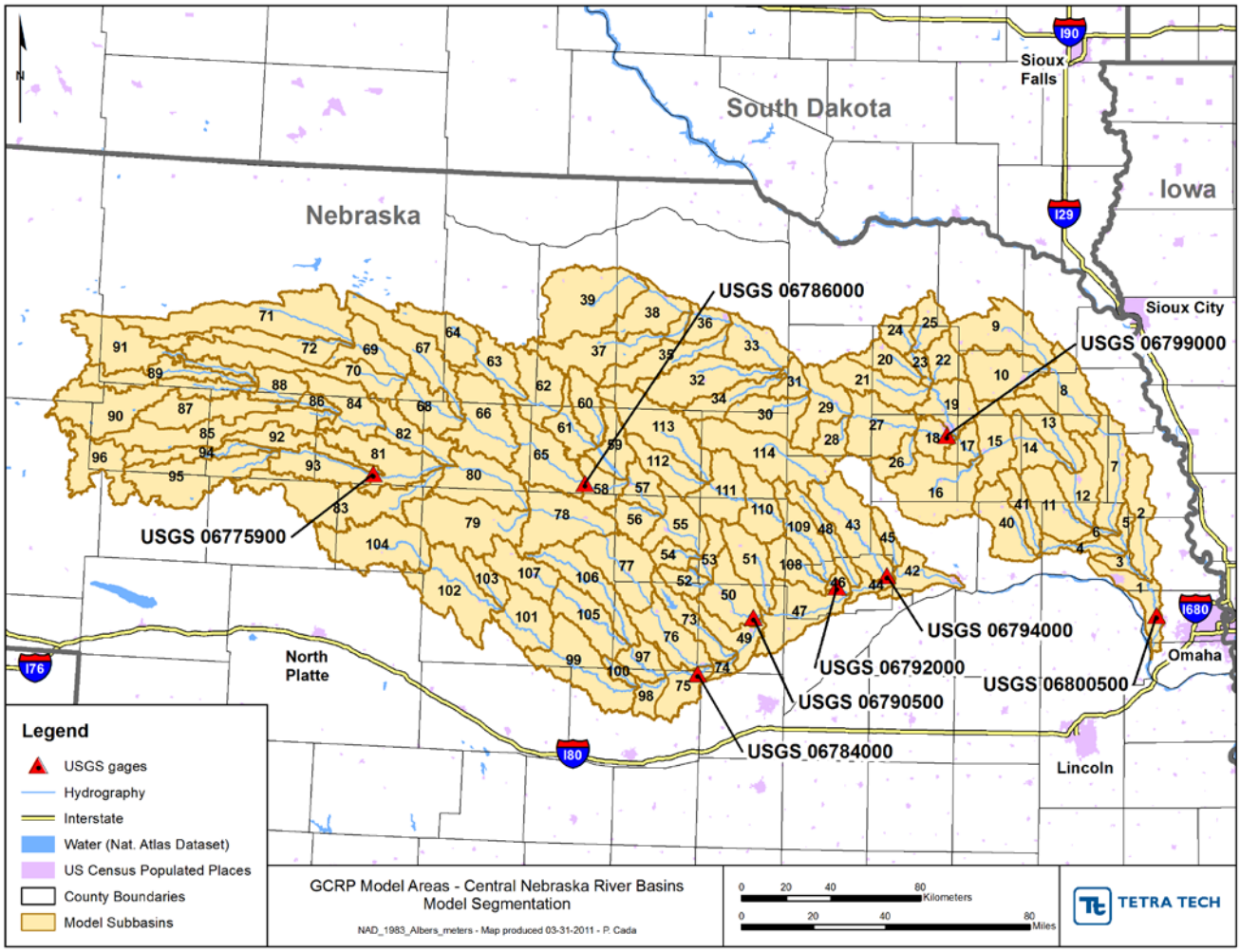

Figure 3. Model segmentation and USGS stations utilized for the Loup and Elkhorn River basins

Calibration Data and Locations

The specific site chosen for initial calibration was the Elkhorn River at Waterloo, NE, a flow and water quality monitoring location at the Elkhorn River outflow to the Platte River. The drainage area for this gage is somewhat larger than those selected for most other 20 Watershed study areas, but is the only station on the Elkhorn that provides both flow and TSS monitoring over long periods of time. The Elkhorn River watershed was selected for calibration focus because of the difficulties in obtaining model fit to the Sandhills area – both in this project and in the earlier USGS modeling effort (Strauch and Linard 2009). Calibration and validation were then pursued at multiple locations (Table 5), including multiple stations such as Dismal River that are entirely within the Sandhills. Parameters derived on the Elkhorn River were not fully transferable to other portions of the watershed; therefore, additional calibration was conducted at multiple gage locations.

Table 5. Calibration and validation locations in the Loup and Elkhorn River basins

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Dismal River near Thedford, NE	06775900	966	X	
South Loup River at Saint Michael, NE	06784000	2,320	X	
Middle Loup River at Saint Paul, NE	06785000	8,075	X	
North Loup River at Taylor, NE	06786000	2,350	X	
North Loup River near Saint Paul, NE	06790500	4,302	X	
Cedar River near Fullerton, NE	06792000	1,220	X	
Beaver Creek at Genoa, NE	06794000	677	X	X
Elkhorn River at Norfolk, NE	06799000	2,790	X	X
Elkhorn River at Waterloo, NE	06800500	6,900	X	X

The model hydrology calibration period was set to Water Years 1989-1999 (within the 30-year period of record for modeling). Hydrologic validation was then performed on Water Years 1978-1988. Water quality data availability is somewhat low for the watershed, and water quality calibration used calendar years 1990-1995, while validation used 1986-1989.

SWAT Modeling

Assumptions

The Sandhills present a major challenge for hydrologic simulation. Previous attempts by USGS (Strauch and Linard, 2009) found that it was very difficult to achieve a good fit to observed flows in the Sandhills region using the SWAT model. Flow in this region of highly permeable soils tends to maintain steady rates driven by groundwater discharge and much of the effort of calibration was focused on obtaining a reasonable representation of this behavior.

There is one major reservoir in the Loup River basin – the Calamus Reservoir, which was included in the model. Two smaller reservoirs (less than 100,000 AF storage) - Sherman Reservoir and Davis Creek Reservoir – were not explicitly modeled. Pertinent information on Calamus Reservoir including surface area and storage at principal (normal) and emergency spillway levels for the reservoirs modeled were obtained from the United Sates Bureau of Reclamation website. The SWAT model provides four options to simulate reservoir outflow: measured daily outflow, measured monthly outflow, average annual release rate for uncontrolled reservoir, and controlled outflow with target release. Keeping in view the 20 Watershed climate change impact evaluation application, it was assumed that the best representation of the reservoirs was to simulate them without supplying time series of outflow records. Therefore, target release approach was used in the GCRP-SWAT model.

The Loup River system has a major water withdrawal (Loup River Power Canal) just before the point of entry into the North Platte River. This withdrawal is represented in the model by monthly average rates and results in substantially lower flows in the Loup River at the mouth than upstream.

Hydrology Calibration

A spatial calibration approach was adopted for GCRP-SWAT modeling for the Loup and Elkhorn River basins. In particular, a distinctly different set of parameters was needed to simulate hydrology in the Sandhills area.

The initial calibration focus area (Elkhorn River) includes 39 subwatersheds, of which about half (the western portion) are in the Sandhills with the remainder more representative of typical plains land use. The Loup River basin also originates in the Sandhills and has similar downstream soils and land uses. The model parameters were adjusted to obtain reasonable fit between the simulated and measured flows in terms of Nash-Sutcliffe modeling efficiency and the high flow and low flow components as well as the seasonal flows.

The water balance was evaluated separately for the Elkhorn and Loup River watersheds. For the Elkhorn, the water balance predicted by the SWAT model over the 32-year simulation period is as follows:

```
PRECIP =    675.6 MM
SNOW FALL =   80.60 MM
SNOW MELT =    79.20 MM
SUBLIMATION =     1.40 MM
SURFACE RUNOFF Q =     0.48 MM
LATERAL SOIL Q =   57.86 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    26.08 MM
REVAP (SHAL AQ => SOIL/PLANTS) =   30.22 MM
DEEP AQ RECHARGE =     8.24 MM
TOTAL AQ RECHARGE =   82.42 MM
TOTAL WATER YLD =    84.42 MM
```

```
PERCOLATION OUT OF SOIL =   84.99 MM
ET =    530.1 MM
PET =   1750.5MM
TRANSMISSION LOSSES =     0.00 MM
```

The water balance for the Loup watershed is summarized as follows:

```
PRECIP =    579.4 MM
SNOW FALL =   77.00 MM
SNOW MELT =    76.25 MM
SUBLIMATION =     0.76 MM
SURFACE RUNOFF Q =     1.15 MM
LATERAL SOIL Q =   10.02 MM
TILE Q =     0.00 MM
GROUNDWATER (SHAL AQ) Q =    45.46 MM
REVAP (SHAL AQ => SOIL/PLANTS) =   25.69 MM
DEEP AQ RECHARGE =    66.73 MM
TOTAL AQ RECHARGE =  156.04 MM
TOTAL WATER YLD =    56.63 MM
PERCOLATION OUT OF SOIL =  158.39 MM
ET =    408.0 MM
PET =   1489.7MM
TRANSMISSION LOSSES =     0.00 MM
```

Hydrologic calibration adjustments focused on the following parameters:

- CN2 (initial SCS runoff curve number for moisture condition II)
- ESCO (soil evaporation compensation factor)
- SURLAG (surface runoff lag coefficient)
- SOL_AWC (available water capacity of the soil layer, mm water/mm of soil)
- ALPHA_BF (baseflow alpha factor, days)
- GW_DELAY (groundwater delay time, days)
- GWQMIN (threshold depth of water in the shallow aquifer required for return flow to occur, mm)
- GW_REVAP (groundwater “revap” coefficient)
- CH_N1 (Manning’s “n” value for tributary channels)
- CH_N2 (Manning’s “n” value for main channels)
- CH_K1 (Effective hydraulic conductivity in tributary channel alluvium)
- CH_K2 (Effective hydraulic conductivity in main channel alluvium)
- SFTMP (Snowfall temperature)
- SMTMP (Snowmelt base temperature)
- SMFMX (Maximum melt rate for snow during the year)
- SMFMN (Minimum melt rate for snow during the year)
- SOL_CRK (Crack volume potential of soil)

Calibration was performed for water years 1990-1999. Results for the Elkhorn River are summarized in Figure 4, Figure 5, Figure 6, Figure 7, and Table 6. The quality of fit is generally adequate, except that late winter/early spring high flow events tend to be underpredicted.

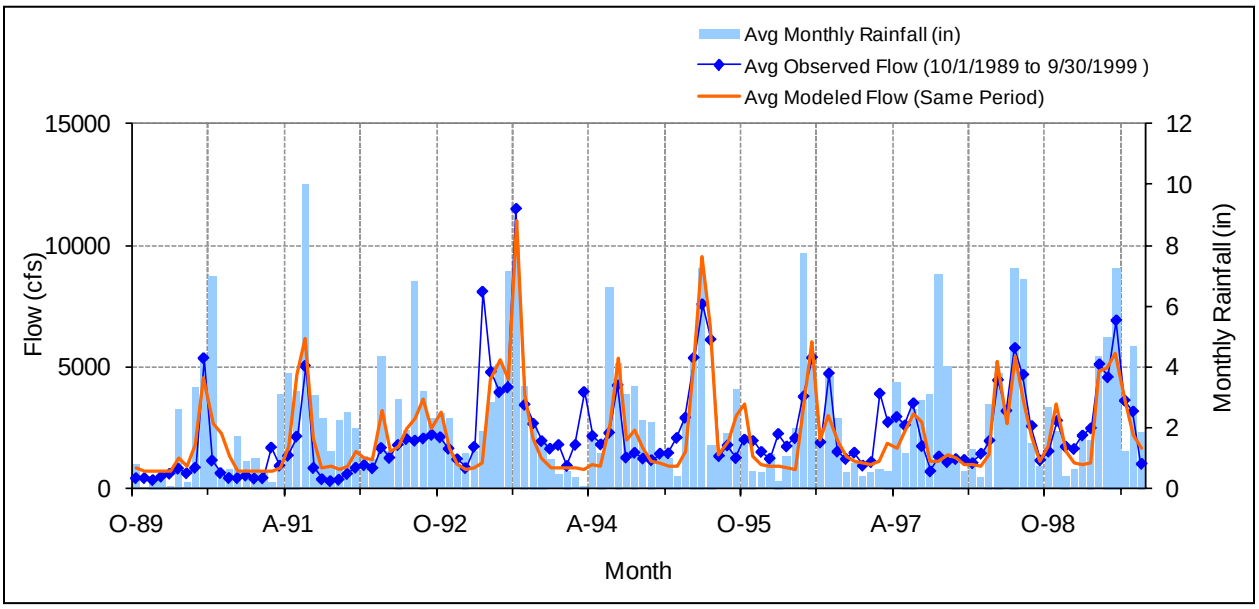

Figure 4. Mean monthly flow at USGS 06800500 Elkhorn River at Waterloo, NE – calibration period

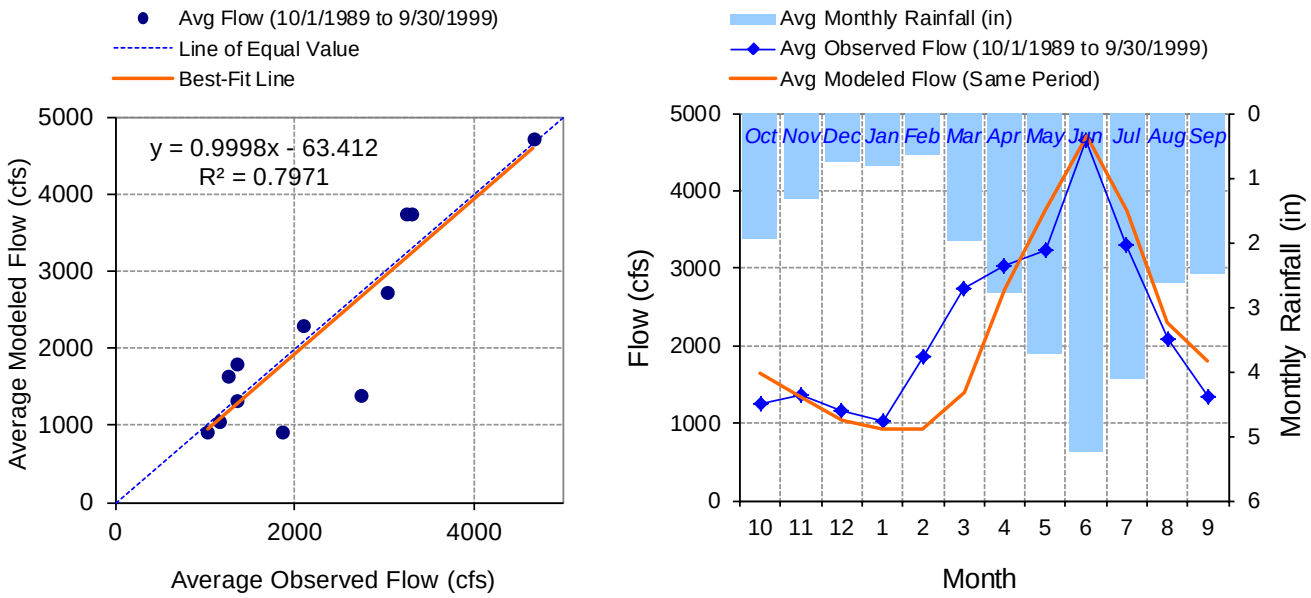

Figure 5. Seasonal regression and temporal aggregate at USGS 06800500 Elkhorn River at Waterloo, NE - calibration period

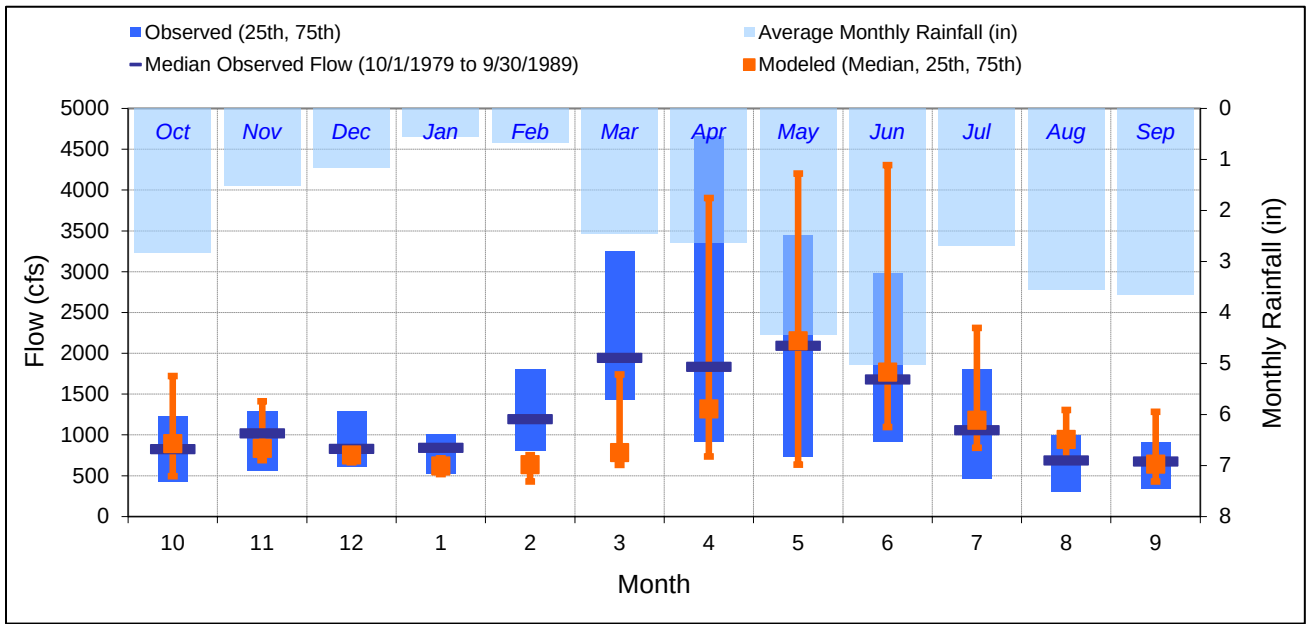

Figure 6. Seasonal medians and ranges at USGS 06800500 Elkhorn River at Waterloo, NE – calibration period

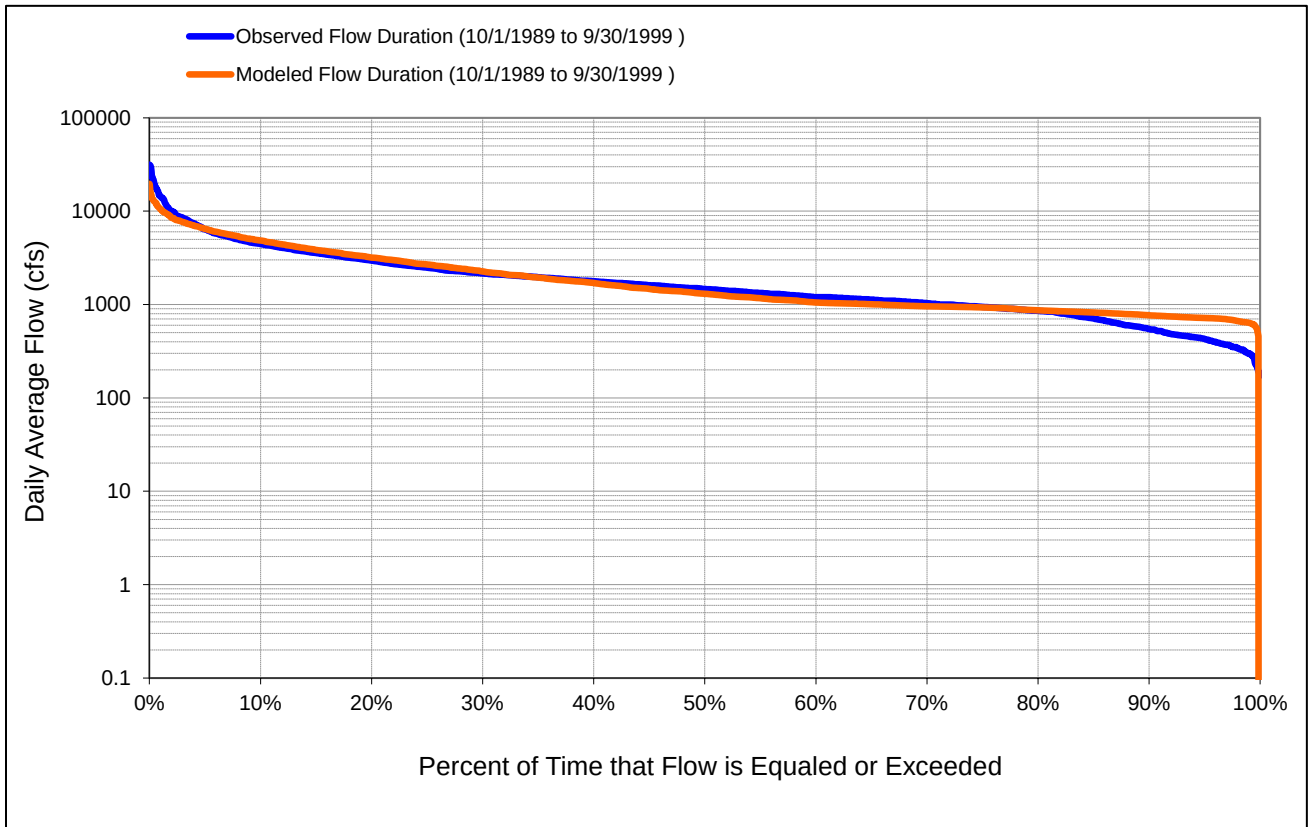

Figure 7. Flow exceedance at USGS 06800500 Elkhorn River at Waterloo, NE - calibration period

Table 6. Summary statistics at USGS 06800500 Elkhorn River at Waterloo, NE - calibration period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 1 10-Year Analysis Period: 10/1/1989 - 9/30/1999 Flow volumes are (inches/year) for upstream drainage area		USGS 06800500 Elkhorn River at Waterloo, Nebr. Hydrologic Unit Code: 10220003 Latitude: 41.2933333 Longitude: -96.2838889 Drainage Area (sq-mi): 6900	
Total Simulated In-stream Flow:	**4.32**	Total Observed In-stream Flow:	**4.43**
Total of simulated highest 10% flows:	**1.43**	Total of Observed highest 10% flows:	**1.64**
Total of Simulated lowest 50% flows:	**0.91**	Total of Observed Lowest 50% flows:	**0.89**
Simulated Summer Flow Volume (months 7-9):	**1.30**	Observed Summer Flow Volume (7-9):	**1.12**
Simulated Fall Flow Volume (months 10-12):	**0.66**	Observed Fall Flow Volume (10-12):	**0.62**
Simulated Winter Flow Volume (months 1-3):	**0.52**	Observed Winter Flow Volume (1-3):	**0.91**
Simulated Spring Flow Volume (months 4-6):	**1.83**	Observed Spring Flow Volume (4-6):	**1.78**
Total Simulated Storm Volume:	**0.97**	Total Observed Storm Volume:	**1.50**
Simulated Summer Storm Volume (7-9):	**0.31**	Observed Summer Storm Volume (7-9):	**0.44**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-2.59	10	
Error in 50% lowest flows:	2.09	10	
Error in 10% highest flows:	-12.56	15	
Seasonal volume error - Summer:	16.30	30	
Seasonal volume error - Fall:	6.89 >>	30	Clear
Seasonal volume error - Winter:	**-42.36**	**30**	
Seasonal volume error - Spring:	2.58	30	
Error in storm volumes:	**-35.47**	**20**	
Error in summer storm volumes:	-30.24	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.416	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.337		
Monthly NSE	0.642		

Hydrology Validation

Hydrology validation for the Elkhorn River was performed for the period water years 1980-1989. The validation achieves a reasonable coefficient of model fit efficiency, but again appears to underpredict winter/spring storm events (Figure 8, Figure 9, Figure 10, Figure 11, and Table 7).

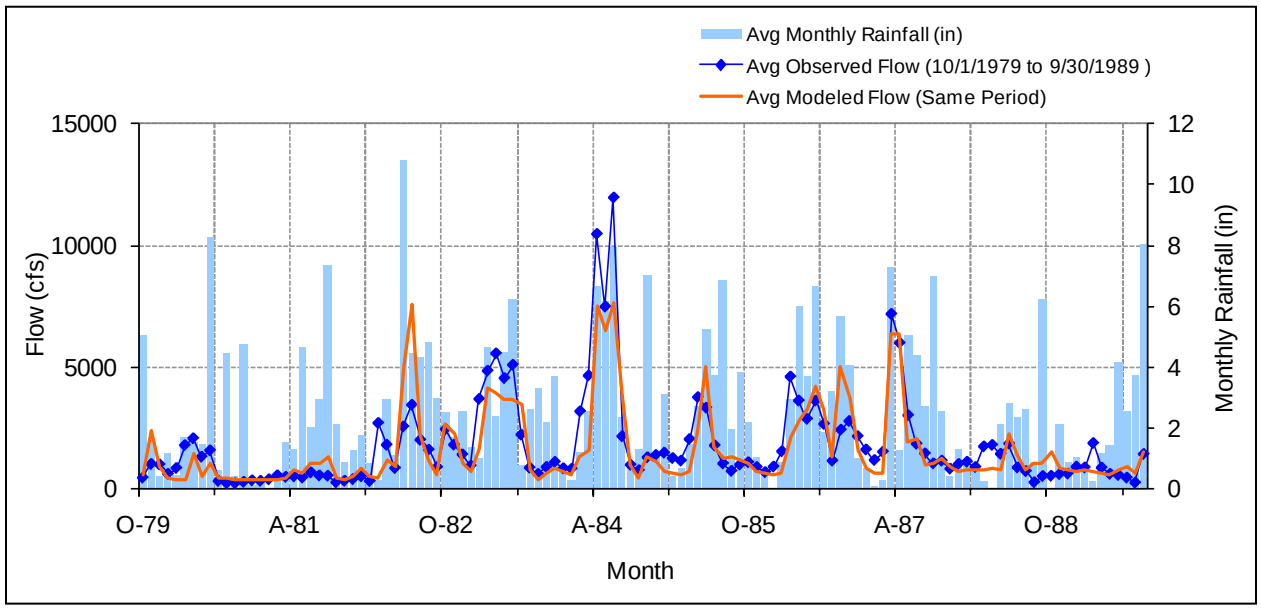

Figure 8. Mean monthly flow at USGS 06800500 Elkhorn River at Waterloo, NE – validation period

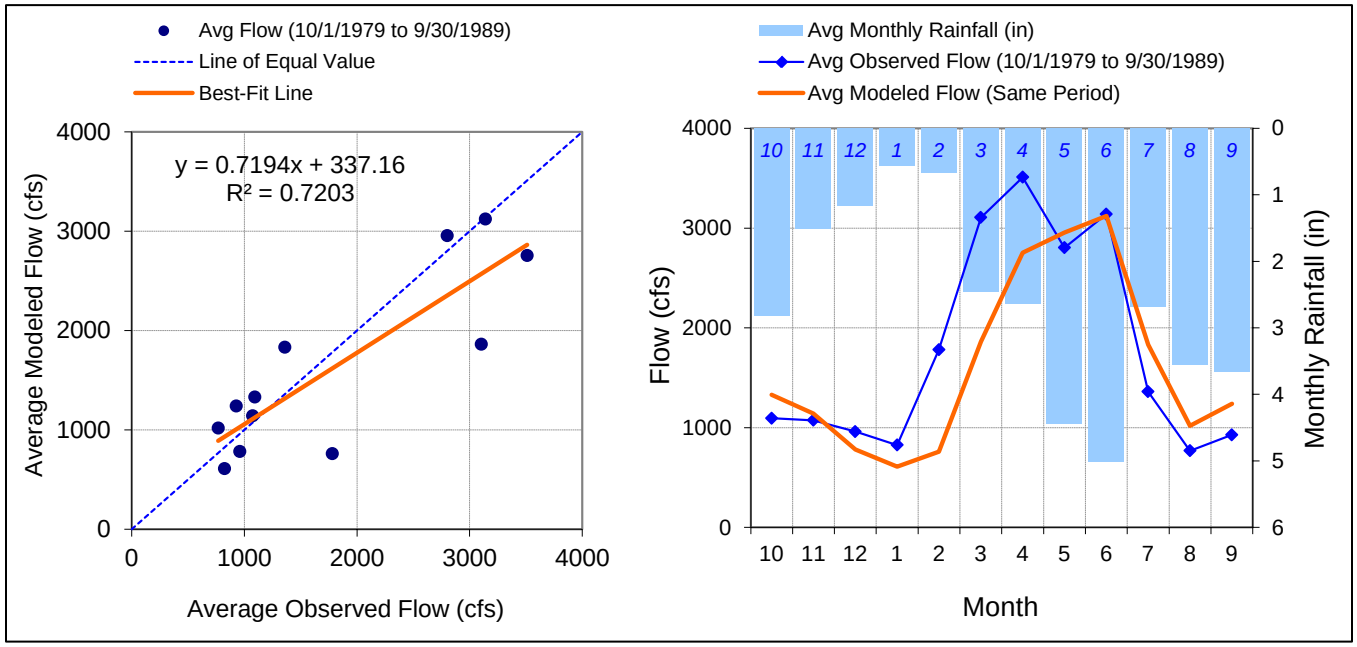

Figure 9. Seasonal regression and temporal aggregate at USGS 06800500 Elkhorn River at Waterloo, NE - validation period

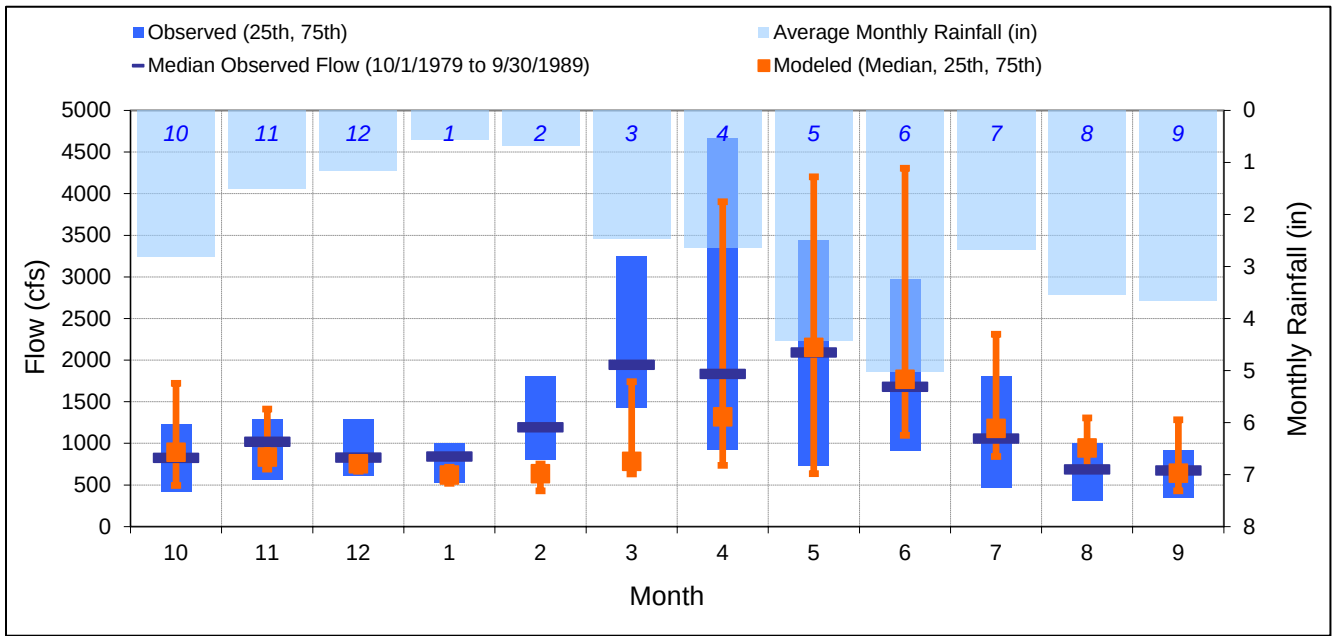

Figure 10. Seasonal medians and ranges at USGS 06800500 Elkhorn River at Waterloo, NE – validation period

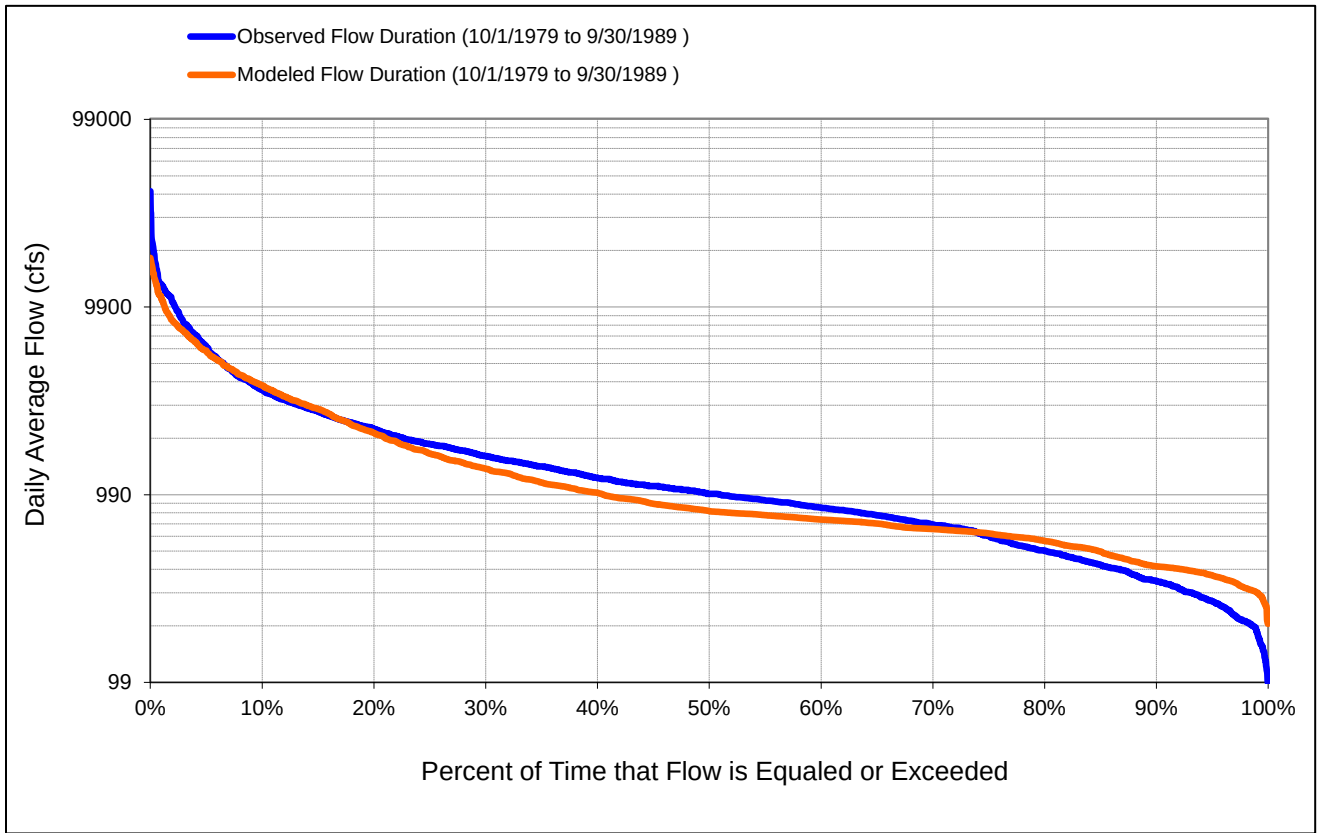

Figure 11. Flow exceedance at USGS 06800500 Elkhorn River at Waterloo, NE - validation period

Table 7. Summary statistics at USGS 06800500 Elkhorn River at Waterloo, NE - validation period

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 1 10-Year Analysis Period: 10/1/1979 - 9/30/1989 Flow volumes are (inches/year) for upstream drainage area		USGS 06800500 Elkhorn River at Waterloo, Nebr. Hydrologic Unit Code: 10220003 Latitude: 41.2933333 Longitude: -96.2838889 Drainage Area (sq-mi): 6900	
Total Simulated In-stream Flow:	**3.19**	Total Observed In-stream Flow:	**3.49**
Total of simulated highest 10% flows:	**1.32**	Total of Observed highest 10% flows:	**1.50**
Total of Simulated lowest 50% flows:	**0.57**	Total of Observed Lowest 50% flows:	**0.58**
Simulated Summer Flow Volume (months 7-9):	**0.68**	Observed Summer Flow Volume (7-9):	**0.51**
Simulated Fall Flow Volume (months 10-12):	**0.54**	Observed Fall Flow Volume (10-12):	**0.52**
Simulated Winter Flow Volume (months 1-3):	**0.53**	Observed Winter Flow Volume (1-3):	**0.93**
Simulated Spring Flow Volume (months 4-6):	**1.44**	Observed Spring Flow Volume (4-6):	**1.54**
Total Simulated Storm Volume:	**0.76**	Total Observed Storm Volume:	**1.23**
Simulated Summer Storm Volume (7-9):	**0.18**	Observed Summer Storm Volume (7-9):	**0.17**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-8.81	10	
Error in 50% lowest flows:	-1.66	10	
Error in 10% highest flows:	-12.33	15	
Seasonal volume error - Summer:	**33.85**	**30**	
Seasonal volume error - Fall:	3.94 >>	30	Clear
Seasonal volume error - Winter:	**-43.05**	**30**	
Seasonal volume error - Spring:	-6.46	30	
Error in storm volumes:	**-38.41**	**20**	
Error in summer storm volumes:	3.39	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.518	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.405	as E or E' approaches 1.0	
Monthly NSE	0.701		

Hydrology Results for Larger Watershed

As described above, parameters determined for the Elkhorn gage were not fully transferable to other gages in the watershed, particularly in the Sandhills area. Calibration and validation was pursued at a total of ten gages throughout the watershed. Calibration results are summarized in Table 8. Those watersheds that are dominantly in the Sandhills area tend to show very low Nash-Sutcliffe coefficients of model fit efficiency for daily flows, but high values for monthly flow volumes, reflecting the complex, groundwater-dominated nature of flow in this area. The quality of fit is comparable to that obtained by Strauch and Linard (2009).

Results of the validation exercise are summarized in Table 9. Results are very similar to those obtained during the calibration period, although total volume is underpredicted at several stations.

Table 8. Summary statistics (percent error): all stations - calibration period

Station	06800500 Elkhorn River at Waterloo	067995000 Elkhorn River at Norfolk	06775900 Dismal River nr Thedford, NE	06784000 South Loup River at St. Michael	06785000 Middle Loup River at St. Paul	06786000 North Loup River at Taylor	06790500 North Loup River nr St. Paul	06792000 Cedar River nr Fullerton	06794000 Beaver Creek at Genoa
Error in total volume:	-2.59	8.47	-4.65	2.43	-3.78	-3.45	-2.07	5.07	-3.41
Error in 50% lowest flows:	2.09	28.72	-8.78	17.14	28.06	-4.99	-5.43	22.91	36.21
Error in 10% highest flows:	-12.56	6.49	1.51	-12.61	-28.75	6.93	-11.58	-12.09	-22.87
Seasonal volume error - Summer:	16.30	46.11	-4.90	26.54	43.95	34.75	0.36	26.71	20.98
Seasonal volume error - Fall:	6.89	20.94	-2.06	19.97	-12.90	-8.31	-6.61	15.37	30.25
Seasonal volume error - Winter:	-42.36	-24.17	-6.22	-13.83	-24.49	-21.70	-19.54	-16.91	-18.95
Seasonal volume error - Spring:	2.58	2.54	-5.45	-10.55	-0.68	-6.25	17.45	-0.34	-23.38
Error in storm volumes:	-35.47	-1.22	-37.60	-48.32	-51.06	-35.46	-44.46	-29.99	-18.33
Error in summer storm volumes:	-30.24	41.15	4.52	-23.62	-21.44	-8.13	-24.44	-22.99	1.85
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.416	0.441	-1.595	0.239	0.206	-0.214	-0.025	0.140	0.032
Monthly Nash-Sutcliffe Coefficient	0.642	0.664	-2.111	0.451	0.252	-0.345	-0.412	0.383	0.356

Table 9. Summary statistics (percent error): all stations - validation period

Station	06800500 Elkhorn River at Waterloo	067995000 Elkhorn River at Norfolk	06775900 Dismal River nr Thedford, NE	06784000 South Loup River at St. Michael	06785000 Middle Loup River at St. Paul	06786000 North Loup River at Taylor	06790500 North Loup River nr St. Paul	06792000 Cedar River nr Fullerton	06794000 Beaver Creek at Genoa
Error in total volume:	-8.81	-15.83	2.93	-27.91	-21.34	-4.72	-5.74	-10.92	-20.87
Error in 50% lowest flows:	-1.66	-7.47	2.36	-29.93	3.64	-0.85	0.74	-17.86	-4.78
Error in 10% highest flows:	-12.33	-8.08	3.36	-28.29	-40.03	-0.84	-15.43	5.04	-28.94
Seasonal volume error - Summer:	33.85	55.96	4.73	-12.53	28.95	35.58	17.91	24.55	1.07
Seasonal volume error - Fall:	3.94	-2.64	1.79	-20.98	-28.56	-15.38	-8.56	-8.54	-2.33
Seasonal volume error - Winter:	-43.05	-40.10	-0.34	-37.75	-40.63	-23.08	-22.61	-27.14	-36.39
Seasonal volume error - Spring:	-6.46	-25.65	5.58	-32.18	-17.24	-0.91	-2.78	-20.96	-30.28
Error in storm volumes:	-38.41	-11.57	-43.85	-51.73	-53.82	-41.29	-39.38	-9.49	-6.55
Error in summer storm volumes:	3.39	125.83	-26.84	-46.64	-25.11	-16.61	-14.87	28.81	-9.23
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.518	0.368	-0.779	0.217	0.105	-0.148	0.031	0.071	-0.051
Monthly Nash-Sutcliffe Coefficient	0.701	0.472	-1.232	0.169	0.022	-0.218	-0.210	0.086	0.149

Water Quality Calibration and Validation

Initial calibration and validation of water quality was done on the Elkhorn River at Waterloo (USGS 06800500), using 1990-1995 for calibration and 1979-1989 for validation. As with hydrology, calibration was performed on the later period as this better reflects the land use included in the model. The start of the validation period is constrained by data availability.

Calibration adjustments for sediment focused on the following parameters:

- SPCON (linear parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- SPEXP (exponential parameter for estimating maximum amount of sediment that can be re-entrained during channel sediment routing)
- CH_COV (channel cover factor)
- CH_EROD (channel erodibility factor)
- USLE_P (USLE support practice factor)

Simulated and estimated sediment loads at the Elkhorn River station for both the calibration and validation periods are shown in Figure 12 and statistics for the two periods are provided separately in Table 10. The key statistic in the Table 10 is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. Table 10 also shows the relative average absolute error, which is the average of the relative magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows better agreement. Overall, TSS loads seem to be somewhat underpredicted due to the representation of scattered spring high flow events. This likely reflects the underprediction of winter/spring storm flow peaks as noted under the hydrology calibration. Elevated TSS loads during these events is likely attributable to primarily channel scour.

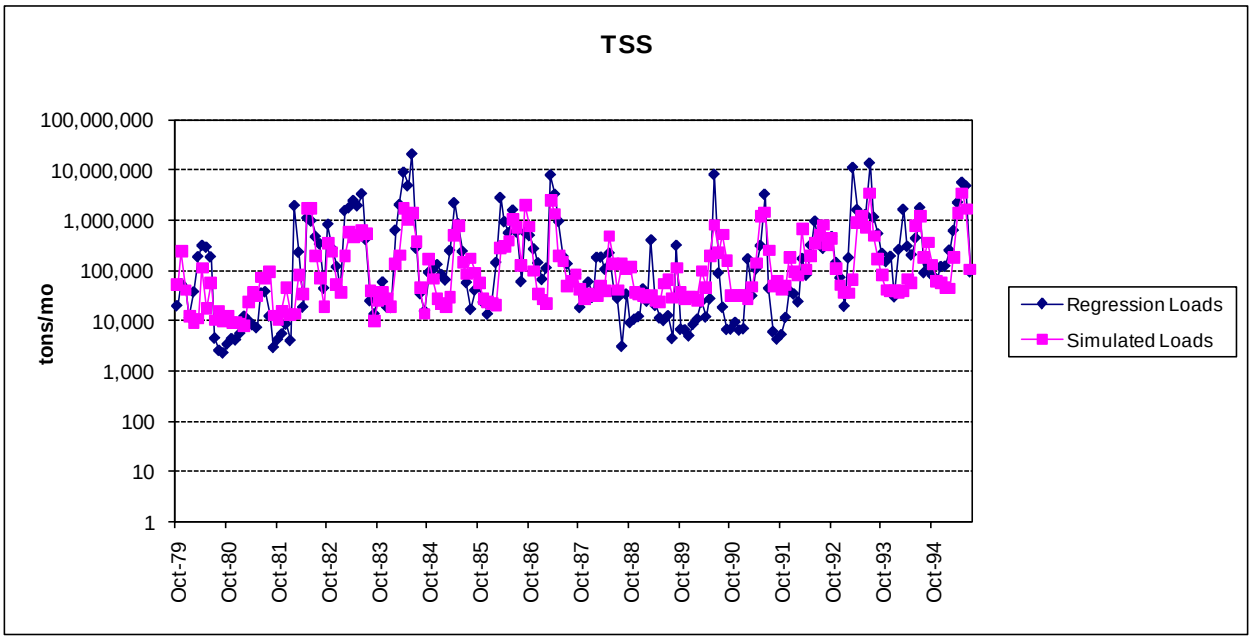

Figure 12. Fit for monthly load of TSS at USGS 06800500 Elkhorn River at Waterloo, NE

Table 10. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 06800500 Elkhorn River at Waterloo, NE

Statistic	Calibration period (1990-1995)	Validation period (1979-1989)
Relative Percent Error	59.6%	66.8%
Relative Average Absolute Error	73.9%	79.5%
Relative Median Absolute Error	14.3%	7.2%

Calibration adjustments for total phosphorus and total nitrogen focused on the following parameters:

- PHOSKD (phosphorus soil partitioning coefficient)
- PSP (phosphorus availability index)
- RS2 (benthic source rate for dissolved P in the reach at 20° C)
- RS3 (Benthic source rate for NH_4-N in the reach at 20° C)
- RS5 (organic P settling rate in the reach at 20° C)
- BC4 (rate constant for mineralization of organic P to dissolved P in the reach at 20° C)
- RS4 (rate coefficient for organic N settling in the reach at 20° C)
- CH_ONCO (Channel organic nitrogen concentration)
- CH_OPCO (Channel organic phosphorus concentration)

Results for the phosphorus simulation are shown in Figure 13 and Table 11. Results for the nitrogen simulation are shown in Figure 14 and Table 12. The model fit reproduces observed seasonal trends, but appears to underpredict total load, reflecting the underprediction of TSS load.

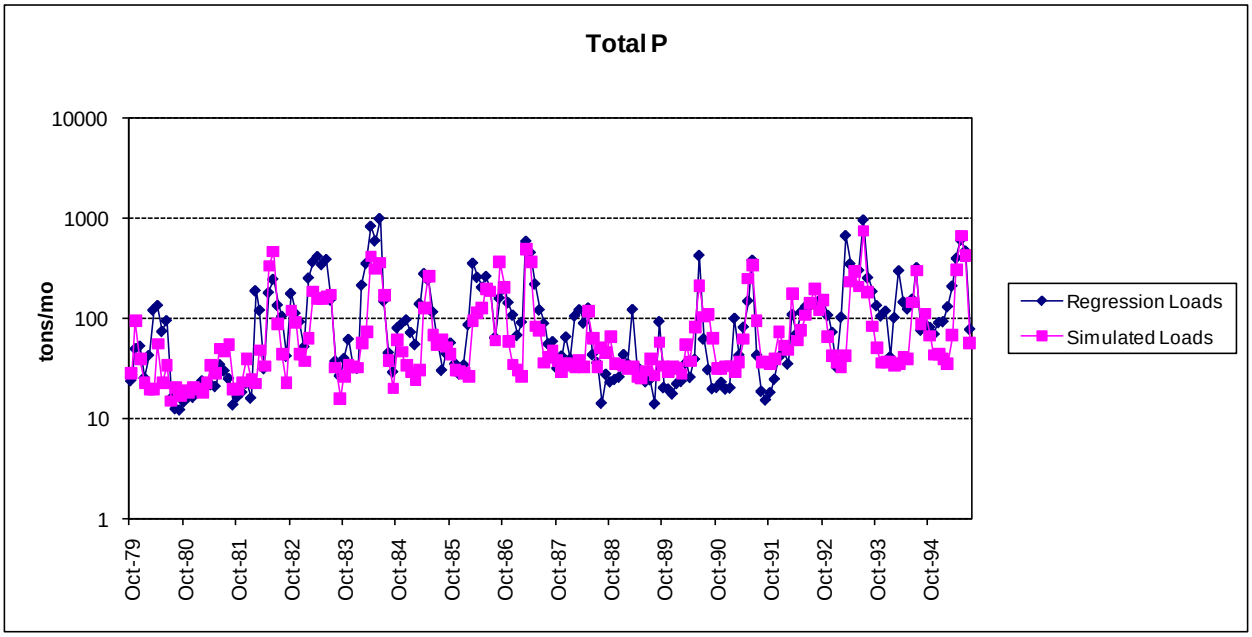

Figure 13. Fit for monthly load of total phosphorus at USGS 06800500 Elkhorn River at Waterloo, NE

Table 11. Model fit statistics (observed minus predicted) for monthly phosphorus loads using stratified regression at USGS 06800500 Elkhorn River at Waterloo, NE

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	24.2%	34.9%
Average Absolute Error	39.8%	49.7%
Median Absolute Error	26.5%	15.6%

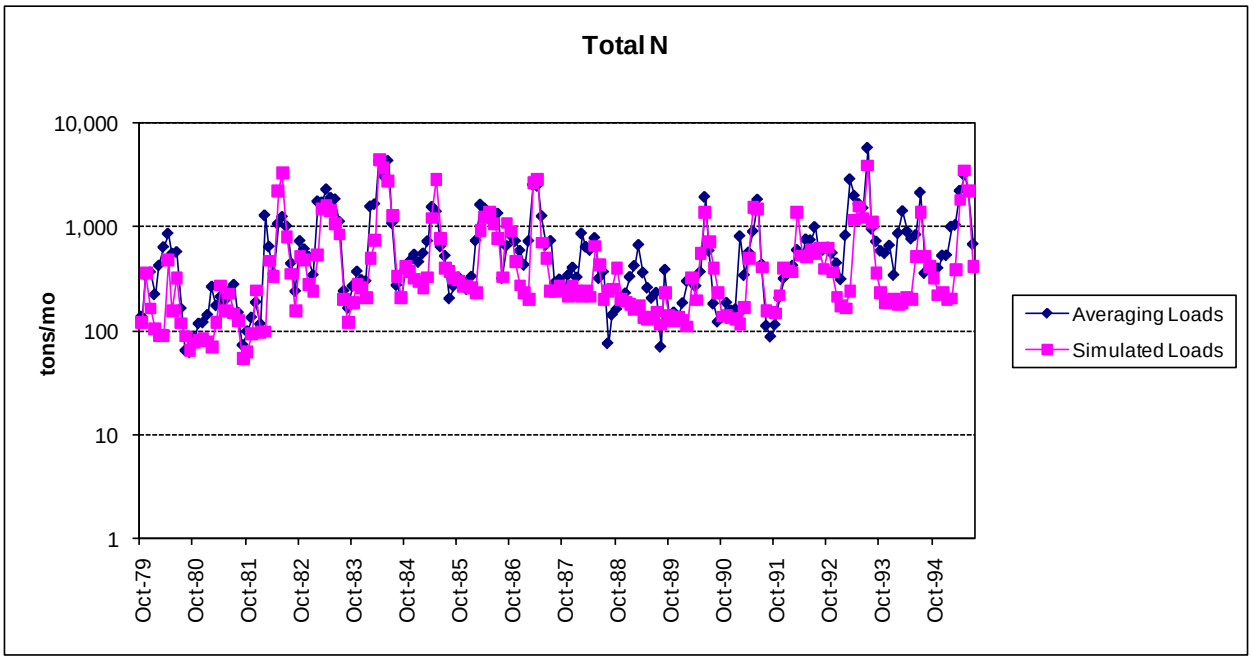

Figure 14. Fit for monthly load of total nitrogen at USGS 06800500 Elkhorn River at Waterloo, NE

Table 12. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator at USGS 06800500 Elkhorn River at Waterloo, NE

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	28.1%	18.1%
Average Absolute Error	39%	38%
Median Absolute Error	22.3%	19.2%

Water Quality Results for Larger Watershed

The Elkhorn River watershed SWAT model parameters for water quality were directly transferred to other portions of the watershed. Only very limited amounts of water quality data are readily available for the remainder of the watershed. Comparison to the data that are available suggests the model may underpredict loads associated with large flow events at other stations as well. Summary statistics for the SWAT water quality calibration other stations in the watershed are provided in Table 13. Insufficient monitoring data were readily available to provide additional validation tests.

Table 13. Summary statistics for water quality at all stations – calibration period 1993-2002

Station	06800500 Elkhorn River at Waterloo	06799000 Elkhorn River at Norfolk	06794000 Beaver Creek at Genoa
Relative Percent Error TSS Load	59.6%	ND	ND
Relative Percent Error TP Load	24.2%	35.8%	54.4%
Relative Percent Error TN Load	28.1%	35.5%	25.3%

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