WR 574 Snow Hydrology

College of Natural Resources
Colorado State University

Fall 2007

Assignment #1: Study Site / Watershed Selection and Overview (*5 marks*)

The first assignment is the selection of a small study watershed that will be used for assignments. The last assignment will be a culmination of the assignment work, with a thorough discussion of the results and implications. While some of the calculations performed for the assignments cannot be validated, i.e., direct measurements do not exist, the last assignment will discuss the appropriateness of the computed numbers. It will summarize the assignments and discuss how realistic the calculated numbers are. Each student will have chosen a study site in a unique state and a discussion at the end of the semester will compare results from the different locations.

Task:

1) Select an appropriate study watershed (see the NCDC meteorological station data summary and the USGS NWIS streamflow archive). The key factors in selecting an appropriate watershed are as follows:
   i) *Snow must be present for at least **three months** of the year*. The water year 2004 will be studied, i.e., October 1st 2003 through September 30th 2004. Consider the location: latitude, elevation, winter temperatures, and precipitation quantities.
   ii) The meteorological station will have hourly data with relatively few missing hours. The following data are required: precipitation (for NCDC hourly data we can assume a Universal gauge with Alter shielding in the winter), air temperature, wind speed and direction, humidity or vapour pressure, cloud cover or radiation (shortwave and longwave or net).
   iii) The meteorological station will be within or near to a corresponding hydrometric station that has daily streamflow data for the same time period. The hydrometric station will gauge a watershed up to 50 km^2. Use your discretion, as flow data will be compare to snowmelt rates for a final assessment of the winter water budget.
2) Download hourly (NCDC unedited) meteorological and daily (USGS) hydrometric data. The final data and results (i.e., spreadsheet) will be submitted with the final assignment (transferred to the user drive or burned onto CD). Convert your data into SI units and use at most 3 significant figures when reporting numbers.
3) Examine land cover / land use maps (from the maps library) or remotely derived imagery (available online through the USGS and related websites). Estimate the amount of forest (or shrubs if no forest) and non-forested area (grass, agriculture, urban, etc.) within 10%. The area of the watershed is available with the hydrometric data.
4) The assignments will be submitted online. The following table lists data and graphs to be submitted. A one-page overview of the watershed will be submitted with the final assignment.

WR574 Assignment #1 - list of submissions

parameter name	short name	submission type	units
location of station (state)	state	words	
meteorological station name	met_stn	words	
meteorological station number	met_num	number	
meteorological station latitude	met_lat	number	decimal degrees (N is +ve)
meteorological station longitude	met_long	number	decimal degrees (W is -ve)
meteorological station elevation	met_z	number	metres
hydrometric station name	q_stn	words	
hydrometric station number	q_num	number	
basin area	d_area	number	square km
hydrometric station latitude	q_lat	number	decimal degrees (N is +ve)
hydrometric station longitude	q_long	number	decimal degrees (W is -ve)
hydrometric station elevation	q_z	number	metres
amount of forested area	area_f	number	%
amount of non-forested area	area_nf	number	%
precip. gauge type = *Universal*	p_gauge	words	
precip. gauge shield = *Alter*	p_shield	words	
precipitation (monthly totals)	precip	image	mm
temperature (avg, max, min)	temp	image	degrees C
wind speed (monthly avg)	wind_v	image	m/s
wind rose direction (annual)	wind_d	image	% in each of 8 sectors
* include on the graph, the % occurrence of *no wind*, and *variable* (VRB) wind direction			
relative humidity (monthly avg)	r_h	image	%
streamflow (daily)	flow	image	m^3/s

Assignment 2: Cloud cover and Precipitation (*5 marks*)

PART I - general questions

1) *Particle fall velocities*: Given precipitation particles of 4mm in diameter, compare the angle at which the particles are falling during a 2 and 4 m/s horizontal wind. Consider rain and snow (plane dendrites, spatial dendrites, powder snow, crystal with droplets and graupel). [***8 marks***]

PART II - using your watershed (plot results on a monthly basis):

2) *Cloud cover and precipitation probabilities*: from the cloud cover and precipitation data, determine i) the monthly frequency of different cloud cover types (clear, few, scattered, broken, and overcast); ii) the average monthly fraction of cloud cover; and iii) the monthly frequency of precipitation (ignoring and including trace events). [***7***]
3) *Synoptic types*: What is the most common storm type to bring winter precipitation for your watershed and why? [***3***]
4) *Precipitation shape and form*: assuming a constant lapse rate and a constant cloud height for your watershed, estimate the monthly distribution of the form of solid precipitation in the clouds. Assume rain for temperature warmer than freezing. [***7***]

Assignment 3: Precipitation Correction and Snowfall (*5 marks*)

PART I - general questions

1) *Wind undercatch*: What was the average wind speed encountered at the mouths of the different gauges at Valdai, Russia between Nov 1991 and March 1992? Use the DFIR (Tretyakov) as the reference. Briefly state the assumptions and/or problems with this estimation. [***8 marks***]

PART II - using your watershed (plot results on a monthly basis):

2) *Precipitation data correction*: using the monthly amount of precipitation, considering trace events (*all future assignments will use this*), determine the monthly amount of precipitation after correcting for wind undercatch and considering trace events. Use 0°C as the threshold for rain/snow. State the assumption for the quantity of precipitation associated with trace events. If multiple gauges are present (eg. Unshielded and Shielded) compare these results as well. [***6***]
3) *Snowfall*: determine the monthly precipitation quantity (mass) that is defined as snow from i) the 0°C rain/snow threshold and ii) based on the mixed precipitation curve that best suits your data. Include the total quantity of precipitation. State which mixed precipitation probability curve that you used, and why. [***11***]

Assignment 4: Accumulation and Snowcover (*5 marks*)

PART I - general questions

1) *Fresh Snow Density*: If 10 mm of snow fell at -1, -6, -10, and -20°C, what would be the fresh snow density using the 4 different curves. [***6 marks***]

PART II - using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

2) *Accumulation*: Assuming that ground temperature is equal to air temperature prior to snowfall and using 0°C as the threshold for initiation of accumulation, determine the following:
   i) when complete snow cover occurs (for this question include 1 assumption required for accumulation; for the project you will need to discuss 2 assumptions regarding the process of accumulation);
   ii) the density of the fresh snow added (use the Hedstrom-Pomeroy curve); and
   iii) the total monthly accumulated snow depth, together with the cumulative snow depth. Assume that rain adds to the mass of snowpack, but not to the depth of snow. [***9***]
3) *Snowcover and Albedo*: Estimate the hourly albedo based on an albedo for soil when there is no snow accumulated, a fresh snow albedo of 0.84, an exponential decay to 0.70 after a snowfall, and an exponential decay to 0.50 during melt, i.e., $T > 0$°C. Plot the monthly average albedo. [***9***]

Assignment 5: Canopy Interception and Redistribution (*5 marks*)

PART I - general questions

1) *Canopy Interception*: If 0.25 mm/h of rain were to fall in the summer and 0.25 mm/h of snow were to fall in the winter, each over a deciduous and coniferous forest, how long would it take for the canopy to reach maximum interception for the 4 cases? [***6 marks***]

PART II - using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

2) *Canopy Interception*: Assume one vegetation type for the vegetated portion of your watershed (% vegetated estimated in the first submission). With a constant leaf area index for the winter and another for the summer (assume June 1st), determine the amount of interception during each storm event, using T=0°C as the threshold between rain and snow. Six hours after the end of a storm event, assume that interception is zero. Estimate the monthly average amount of interception (for all hours) and the monthly average interception during storm events. [***9***]
3) *Redistribution*: Using a threshold wind speed based solely on temperature, determine the monthly occurrence of blowing snow. Using the Pomeroy total transport equation, estimate the monthly total quantity of blowing snow. [***9***]

Assignment 6: Sublimation (*5 marks*)

PART I - general questions

1) *Density of Air*: Determine an equation for the density of air as a function of temperature. [***4***]
2) *Blowing Snow Sublimation*: For a fetch distance of 500 m and a constant solar radiation flux of 120 W/m^2, determine the daily blowing snow sublimation at temperatures of -1, -10, and -30°C with 50, 70 and 90% relative humidity for winds blowing at 5, 10 and 20 m/s. [***6***]
3) *Snowpack Sublimation*: Derive a generalized expression for sublimation. Show your derivation with assumptions. [*7*]

PART II - using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

4) *Snowpack Sublimation*: Apply the generalized expression for sublimation to determine the snowpack sublimation. Plot the monthly sublimation (in *mm of water*). [*7*]

Assignment 7: Snowpack Metamorphosis (*5 marks*)

PART I - general questions

1) *Snowpack Metamorphosis*: How long will it take for the Gold and first order functions to achieve the same density starting with an initial density of 190 kg/m^3 and a maximum density of 250 kg/m^3? The elapsed time in the Gold function and the time step in the first order function are in hours. [***4***]

PART II - using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

2) *Snowpack Metamorphosis*: Use the first order expression to model the densification of a snowpack. Allow the new snow to fall at its fresh snow density and determine the new snowpack depth as a function of the old snow and fresh snow. Plot the average monthly snow depth (in *m*) and snowpack density (in *kg/m^3*). [***14***]
3) *Sublimation and Metamorphosis*: Determine the average monthly snow depth (in *m*) and SWE (in *mm of water*) considering sublimation losses computed for Assignment 5. [***6***]

Assignment 8: Radiation and Energy Balance (*5 marks*)

Using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

1) *Longwave Radiation*: Compute the net longwave radiation and plot the monthly average. [***6***]
2) *Shortwave Radiation*: Using the hourly albedo estimated in Assignment 2, compute the net shortwave radiation and plot the monthly average. [***12***]
3) *Snowpack Internal Energy*: From the air temperature, estimate the net (+/-) hourly energy added to the snowpack. Assume that snow falling at warmer than 0^{o}C will have a temperature of 0^{o}C, and that rain falling at colder than 0^{o}C will have a temperature of 0^{o}C. Use rain at 0^{o}C as the datum of zero energy. Plot the monthly average. [***8***]

Assignment 9: Snowmelt (*5 marks*)

PART I - general questions

1) *Snowmelt Phase*: How much energy is required in each phase of snowmelt to completely melt at 2 m deep snowpack that is at 0^{o}C at the bottom and -12^{o}C at the top with a linear temperature profile. The maximum volumetric water content is a function of the average density of 400 kg/m^3. [***6***]

PART II - using your watershed, perform calculations on an hourly basis and summarize as monthly averages for the winter period, unless otherwise noted:

2) *Energy Balance*: Determine the net hourly energy balance from the longwave, shortwave and snowpack internal energy. Plot the monthly average. [***6***]
3) *Snowmelt*:
   i) From the net energy balance, determine the hourly snowmelt rate. Plot the monthly total snowmelt. [***7***]
   ii) *Snowmelt*: From the hourly snowmelt rate determine using the net energy balance, calibrate the monthly temperature index melt factors. Plot these values. [***6***]

Assignment Synthesis: Watershed Summary (*10 marks*)

From the eight assignments in the WR 474 class, summarize your watershed as follows:
1) provide a 1 page written overview of the watershed
2) in 1 paragraph each, include the monthly plots and discuss the importance of the following:
   i) trace precipitation events
   ii) correction of gauge data for wind undercatch
   iii) amount of precipitation that falls as snow vs. that falls as rain
   iv) how snow accumulation is represented
   v) representation of fresh snow density
   vi) the albedo or snow
   vii) canopy interception, redistribution, and snowpack sublimation as a function of total accumulated SWE
   viii) snowpack depth before and after the consideration of sublimation
   ix) monthly longwave and shortwave radiation and internal snowpack energy
   x) snowmelt
3) considering the size of your watershed compare the cumulative snowmelt (until there is no more snow) to the cumulative streamflow. Discuss the differences in timing and magnitude, if any.

Paper Review (*15 marks*)

Presentation: You will lead the discussion of one to three papers over the course of the semester. You will choose these papers individually with input from the instructor. Each paper will be chose by the morning of the week prior to its discussion so that the instructor can arrange to make copies.

Summary: For each paper presented, you will prepare a written summary of the paper (~1-2 pages) and of the discussion (~1 page).