Exam Land Surface Hydrology
Thursday, 6 November 2014
Duration: 13.30 to 16.30 – Ruppert A

The use of pocket calculators is allowed. The back of this page is the sheet with formulas.

At the end of the session hand in your answer sheet, graded paper and this exam. Write your student number on all the sheets you eventually hand in.

This exam consists of six questions and numerous sub-questions. **You have to answer four full questions. Questions 1, 2 and 3 are compulsory, one of questions 4, 5 or 6 is optional. The overall mark is assessed relative to the total score of your selected questions. Clearly indicate which questions should be marked on the first sheet of your exam. In case of ambiguity, the three compulsory questions and the first additional one will be marked.**

Do not lose too much time on a specific question but continue with the next. If you skip a question or answer it later on, please indicate this.

If you think you need to know the answer to a previous question to answer the next, assume a value yourself and state this clearly in your answer and continue.

Motivate your answers but be as concise as possible. Answers should be given in English. Please write clearly! Unreadable answers are incorrect.

People having a study contract (e.g., registered dyslexics) are entitled to 30 minutes additional exam time. Clearly indicate this on your exam papers.

Good luck!

Rens van Beek

Equations LSH examination:

Reynolds number $$\mathrm{Re} = \frac{v \cdot L}{\nu}$$

Froude number $$\mathrm{Fr} = \frac{v}{\sqrt{gD}}$$

Bernoulli's equation: $$\frac{\overline{v^2}}{2g} + \frac{P}{\rho g} + z = \text{constant}$$

Manning: $$Q = A \cdot V_{avg} = \frac{A \cdot R^{2/3} \cdot S^{0.5}}{n}$$

Chezy: $$Q = A \cdot V_{avg} = A \cdot C \cdot (R \cdot S)^{0.5}$$

Muskingum

$$O_2 = c_0 I_2 + c_1 I_1 + c_2 O_1$$
$$c_0 = (- KX + 0.5*\Delta T) / (K - KX + 0.5*\Delta T)$$
$$c1 = (KX + 0.5*\Delta T) / (K - KX + 0.5*\Delta T)$$
$$c2 = (K - KX - 0.5*\Delta T) / (K - KX + 0.5*\Delta T)$$

+ Cunge

$$c = m*v$$
$$K = \Delta x / c$$
$$X = 0.5 * [1 - Q_0 / (S_0 * B_0 * c * \Delta x)]$$

St. Venant $$S_f = S - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t}$$

Linear reservoir $$Q_t = Q_{t-1} \cdot e^{-dt/k} + I_t \cdot \left(1 - e^{-dt/k}\right)$$

$$Q_t = \frac{k - \frac{1}{2}\Delta t}{k + \frac{1}{2}\Delta t} Q_{t-1} + \frac{\Delta t}{k + \frac{1}{2}\Delta t} I_t$$

Curve Number $$Q = \frac{P^2}{P+S},$$

$$CN(II) = 1000/(10+S)$$

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}, \quad CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)}$$

where I corresponds to dry, II to normal and III to wet conditions.

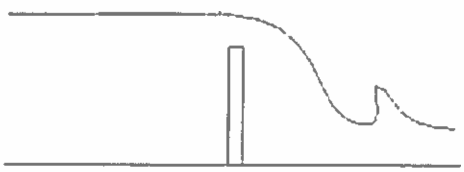
Question 1: Theory (25 points in total, equally divided)

a) Explain the difference between effective and excess precipitation and list two methods to convert total event rainfall into excess precipitation.

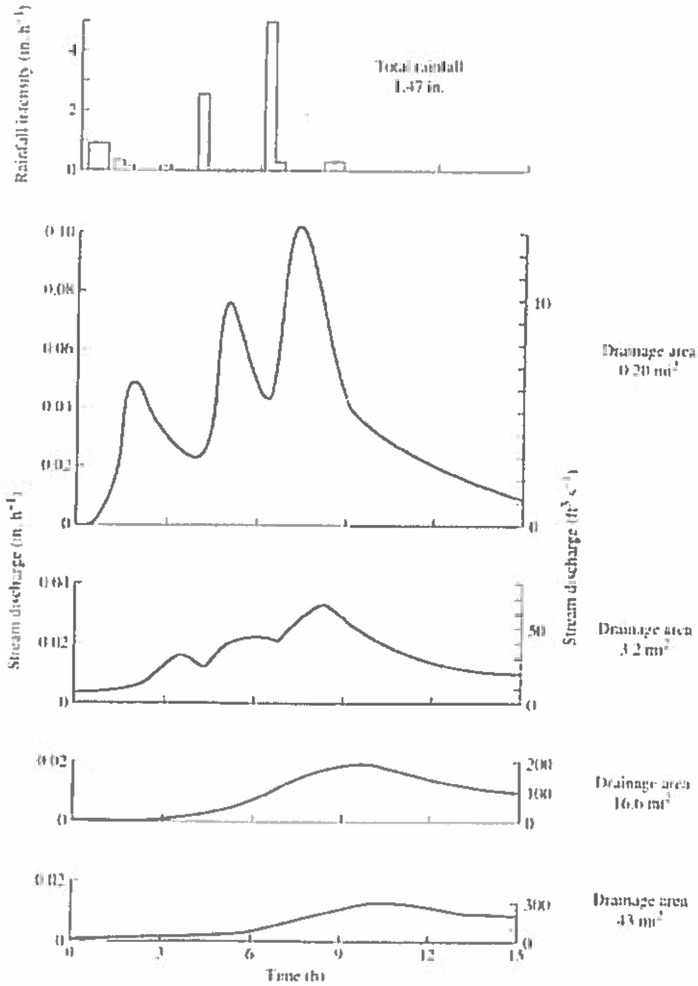
b) Explain the concept of cold storage in relation to snow melt modelling and the subsequent two phases governing snow melt.

c) Compared to simpler degree-day factor models to simulate snow melt, methods based on the energy balance have a stronger physical basis. However, it is not without problems. List two drawbacks of the energy balance approach.

d) Explain the meaning of the Froude number, starting from its equation. Indicate in the following cross-section of a weir the three flow domains the Froude number distinguishes.



e) Shown below is the response at Sleeper's River with the stream response for sub-catchments of different size. Describe the processes that dominate the runoff response at each scale (1 inch= 25.4 mm, 1 sq. mile= 2.59 km^2).



Question 2: UH & Linear Reservoir (Total 30 points, a= 12, b= 6, c= 6; d= 6)

Given are the measured discharge and effective precipitation for a 3.2 km^2 large catchment.

Time [day]	**P** [mm]	**Discharge** [l/s]	**Time** [day]	**P** [mm]	**Discharge** [l/s]
1		68	11		98
2	35	64	12		89
3		147	13		86
4		280	14		80
5		229	15		75
6		191	16		71
7		156	17		65
8		131	18		61
9		116	19		58
10		105	20		54

a) Determine the Unit Hydrograph in terms of *excess precipitation* for the event on day 2 delivering 35 mm of *effective precipitation.*

b) What is the change in storage (in m^3) on day 9 relative to day 2 assuming that the linear reservoir model applies for the groundwater reservoir?

The following has no direct relation to the above:

c) A basic assumption of the UH is linearity. Give one reason why the assumption of linearity may be violated in respectively the short-term and long-term.

d) Two S-curves, derived for a 1-mm 1-hour unit hydrograph, are used to obtain the 6-hour unit hydrograph by shifting the origin of one to t= 6 hours and subtracting it from the one centred at t= 0. . Directly after subtracting the one S-curve from the other, does the area under the curve contain 1 unit of excess precipitation?

Question 3: Routing (Total 30 points; a= 10; b= 6; c= 6; d-g= 1 each; h= 4)

The wave celerity in hydraulic routing schemes is given by $c = mv$ where m is $5/3$ for flow subject to Manning friction.

a) Show that $c = mv$, starting from the general form of the momentum equation, $Q = bA^m$, that relates the wetted cross-sectional area, A, to discharge, Q.

b) Given here is the momentum equation for 1-D flow without lateral inflow, the so-called St.Venant equation:

$$S_f = S - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t}.$$

Provide a physical interpretation of the following four terms of the equation: S_f, S, dy/dx and [(v/g)(dv/dx) – (1/g)(dv/dt)].

c) Name the three hydraulic routing methods derived from the St-Venant Equation and specify for each of them whether the common flow condition is assumed to be either steady or non-steady and the water surface profile to be uniform or non-uniform (sketch if necessary).

Consider a rectangular channel of 75 m wide, with a bed slope of 0.5% and a Manning's n of 0.04. You may use the shallow flow approximation. For the situation that the channel discharges 180 m^3/s, compute:

d) The water height;

e) The water velocity, v;

f) The kinematic wave celerity, c_k;

g) The dynamic wave celerity, c_d.

Assume kinematic flow conditions and an increase in discharge from 180 to 200 m^3/s.

h) Using the characteristic method, compute the time at which kinematic shock occurs (hint: compute the distance first).

Question 4: Muskingum-Cunge (Total 25 points; a= 5; b= 5; c= 10; d= 5)

a) For the Muskingum hydrological routing scheme, explain the special cases that arise if the parameter X assumes values of respectively X= 0 and X= 0.5?

Imagine a channel reach of a river with a length of 30 km. From data for a previous flow event, the Muskingum-Cunge parameters K and X were calculated to be respectively 1.5 [hours] and X= 0.30 [-].

b) What is the celerity by which the flood wave travels through the channel?

c) In the headwaters of this reach a rainstorm delivers the input hydrograph given below. What is the resulting hydrograph at the end of this reach?

Input hydrograph for first river stretch. Initial discharge at the end of the reach is 450 m^3/s

Time [hr]	1	2	3	4	5 and later
Input hydrograph Q (m^3/s)	475	550	500	450	450

d) Unrelated to the event under (b, c): Suppose that upstream of this reach a dam of mine tailings would fail, with a substantial amount of contaminated water and pollutants spilling into the river. Would the contamination reach our observation point at 30 km earlier or later than the peak of the flood from this burst? Explain your answer.

Question 5: Bernouilli and specific energy (25 points in total: a: 3; b: 5; c: 12; d: 5)

a) What is the difference between total energy head and specific energy head?

b) List the three basic assumptions of the Bernouilli Equation.

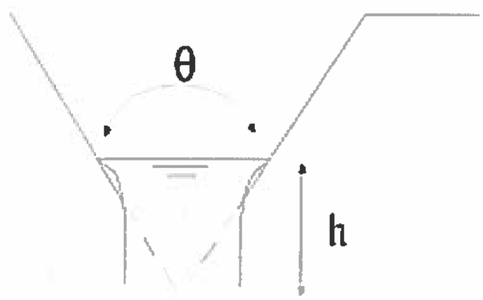
Weirs and flumes are typical discharge measuring structures attaining a large accuracy.

c) Starting from the specific energy equation, derive the stage-discharge relationship for a submerged discharge-measuring device, e.g., a broad-crested weir: $Q = c \cdot b \cdot h^{3/2}$.

d) Starting from the above equation for a broad-crested weir, show that for a V-notch weir:

The general discharge equation for 'V'-notches is:

$$Q = c \cdot \tan\left(\tfrac{1}{2}\theta\right) \cdot h^{5/2}$$



Question 6: Water management (25 points in total: a: 7; b: 6; c: 6; d= 6)

You are asked to contribute to a development project by designing two reservoirs for water supply in a large basin. Both are located on different tributaries that have the same mean discharge but one is semi-arid whereas the other is more humid. The reservoirs have to be designed to the same qualifications, meaning that they have to provide the same safe yield (Q70, exceeded 70% of the time).

a) Sketch (!) proportionally two flow-duration curves next to one another, one for the semi-arid, one for the humid stream- prior and after construction of the reservoir. Indicate the safe yield and the corresponding increase in discharge. Briefly explain your considerations.

At the intended dam locations, the mean discharge for both rivers is 350 $m^3 \cdot s^{-1}$ and the coefficient of variation 29% and 49% for the sub-humid and semi-arid basins respectively.

$$D_p = 1 - \frac{(z_p)^2 (CV_Q)^2}{4\left(T_R + g_p (CV_Q)^2\right)}$$ PH 10.13

Where the draft, $D_p = Y_p / \mu_Q$.

b) Use the formula of McMahon (PH Eq. 10-13) to compute the safe yield for a reservoir with a residence time of 2 years. Assume the correction factor g_p is 1 and z_p= 1.96 (97.5% reliability).

c) Please explain whether the reservoir in the sub-humid region would be more reliable than that in the semi-arid one, or not.

d) What do you believe to be the main point of criticism on the concept of safe yield? Briefly explain your answer.