Atlases of Minnesota Water Sustainability: Creation from Models, Analytical Methods, & Database of Watershed Characteristics

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SDSU

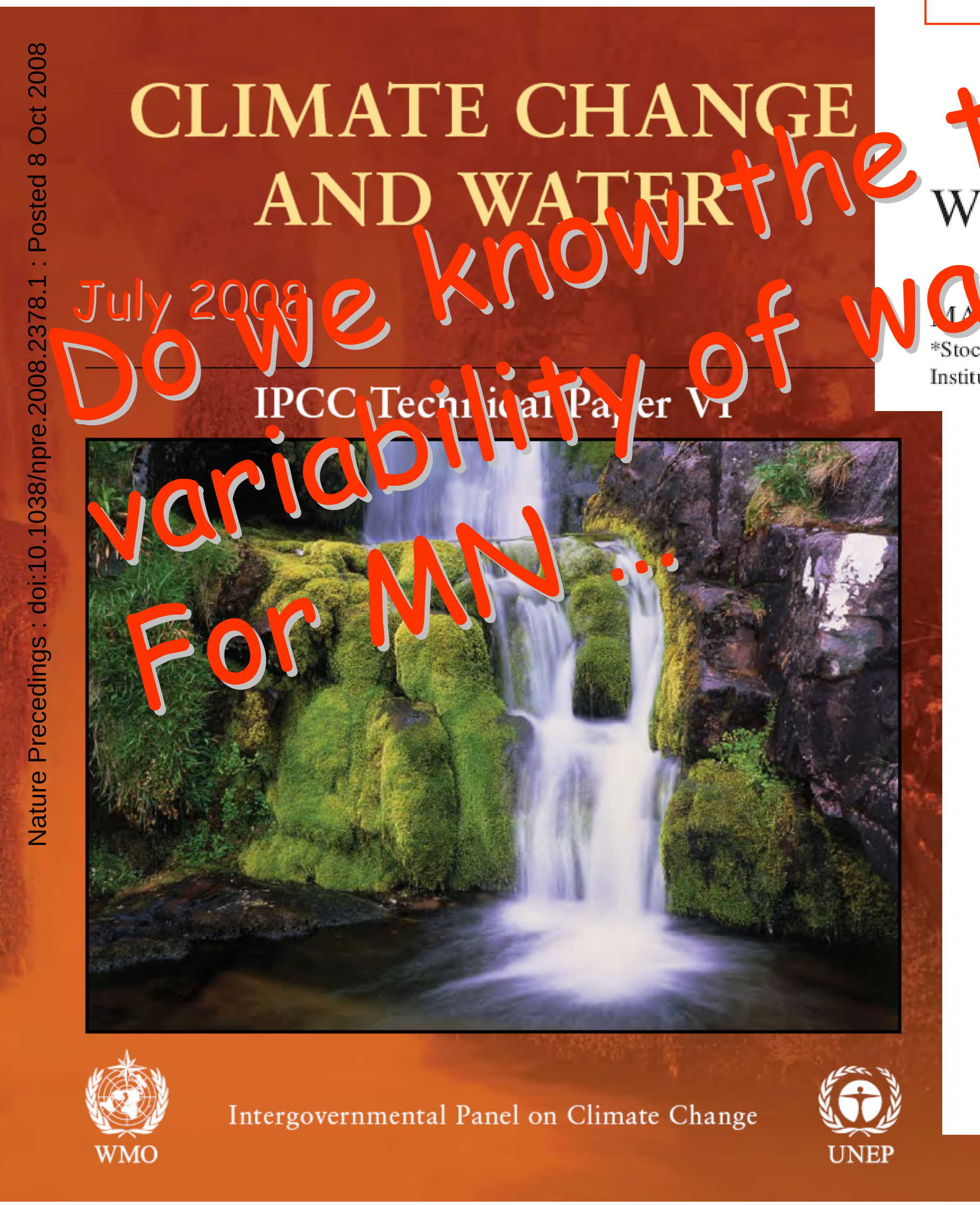
Topics

- Introduction
- Model of 3D watershed & watershed characteristics
- Data (hydrologic, numeric & classification) & philosophy of analysis
- Analysis stream runoff in MN for period 1955-79
- Maps for Eastern Central MN & TC area
- Maps & Regime – units & boundaries
- Questions

Introduction

Do we know the time spatial variability of water resources ?

For MN ...



Water Resources Development,
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Routledge Taylor & Francis Group

Wake Up to Realities of River Basin Closure

MALIN FALKENMARK* & DAVID MOLDEN**

*Stockholm International Water Institute (SIWI), Stockholm, Sweden; **International Water Management Institute (IWMI), Colombo, Sri Lanka

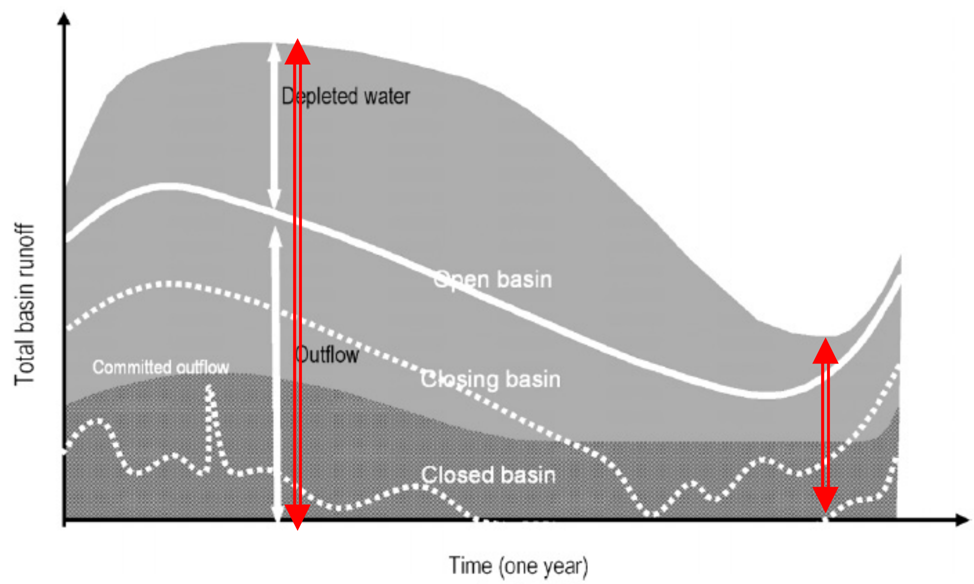
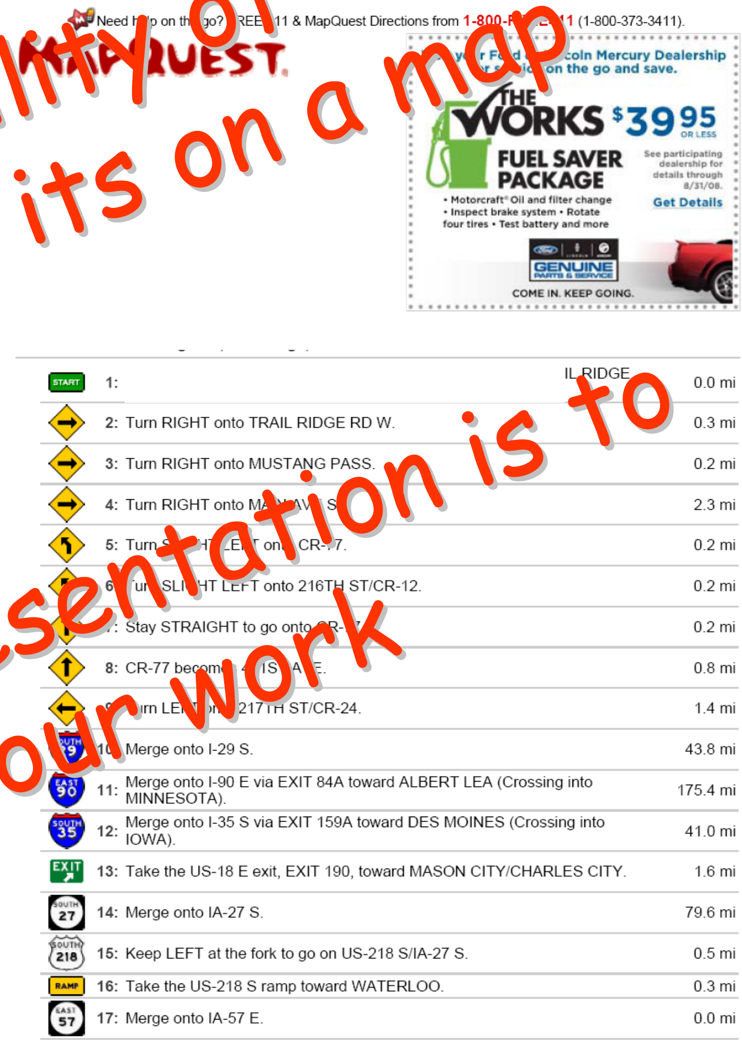


Figure 1. The process of closure over time. In open basins more water can be allocated and diverted, while in a closed basin, flows are over-allocated and diversions of water have impacts on the levels committed for environmental flows and downstream users. *Source:* From Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture (http://www.earthscan.co.uk)

Sustainability of ground water resources on a map (units & boundaries)

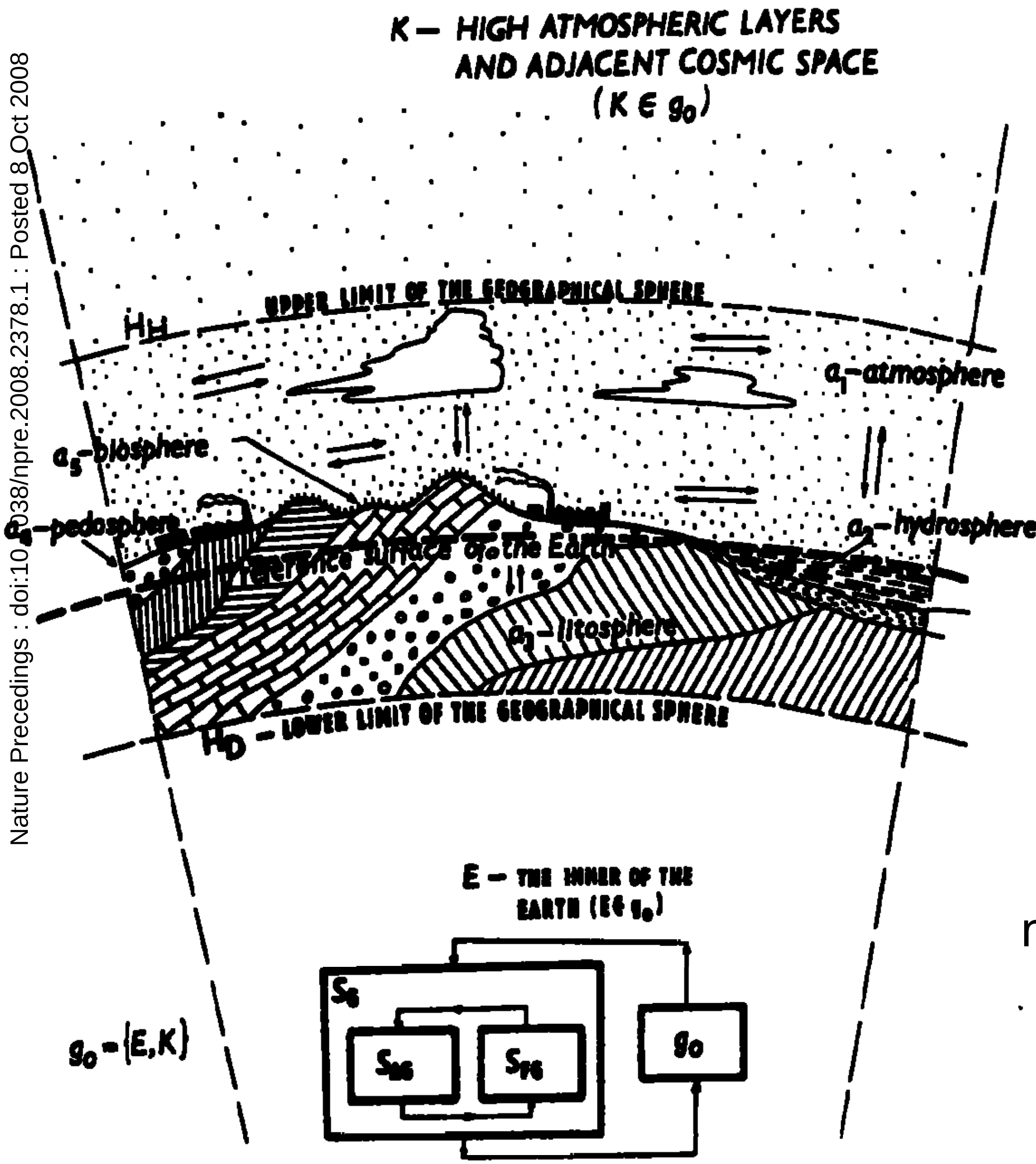
The goal of research is to describe spatial temporal variability of water recourses & put its on a map



The goal for my presentation is to tall a story about our work

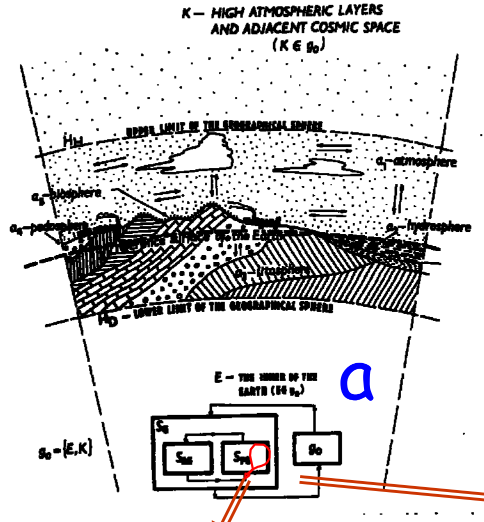
Nature Precedings : doi:10.1038/npre.2008.2378.1 : Posted 8 Oct 2008

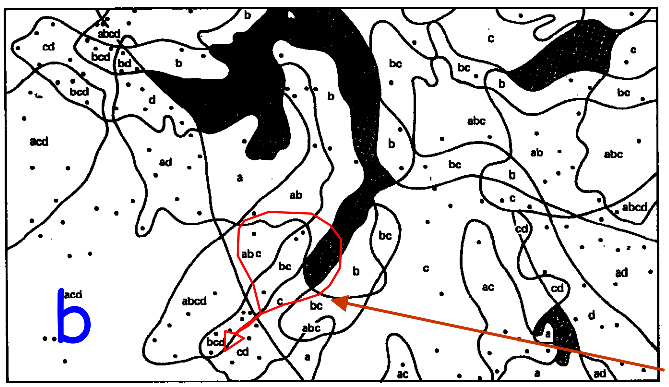
Model of 3D watershed – hydrologic structure

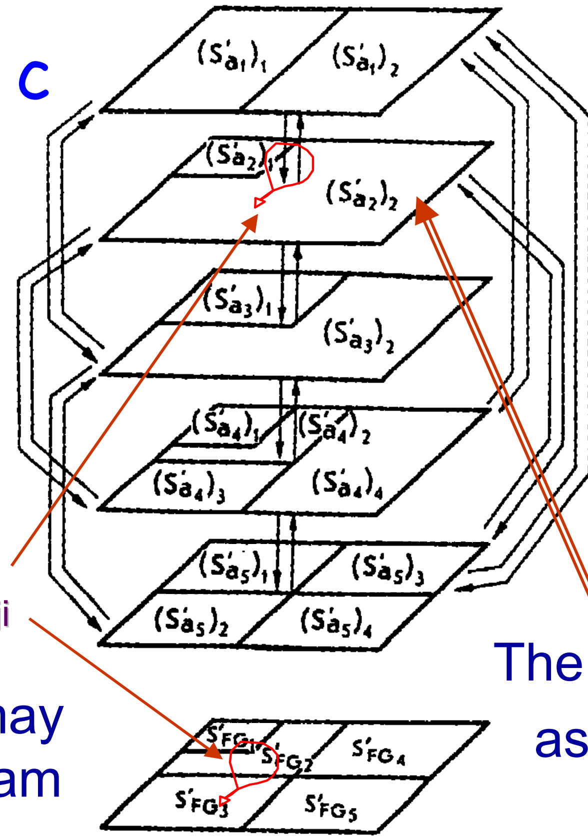


Vertical slice of the Geographical Sphere with two independent elements: System of Anthropological Geography (S_{AG}) & System of Physical Geography (S_{FG}). Arrows indicate vertical & horizontal components of matter, energy & information circulating (after Krcho, 1978)

System Model (a) for Watershed in Landscape, with Map of Conditions (b) & Multilayer Map (c)







g_{ji}

System of Physical Geography Sphere (S_{FG}) with five independent elements:
a_1- atmosphere,
a_2- hydrosphere,
a_3- lithosphere,
a_4- pedosphere,
a_5- biosphere.

The g_2 - stream runoff system as a part of a_2- hydrosphere may be presented as:

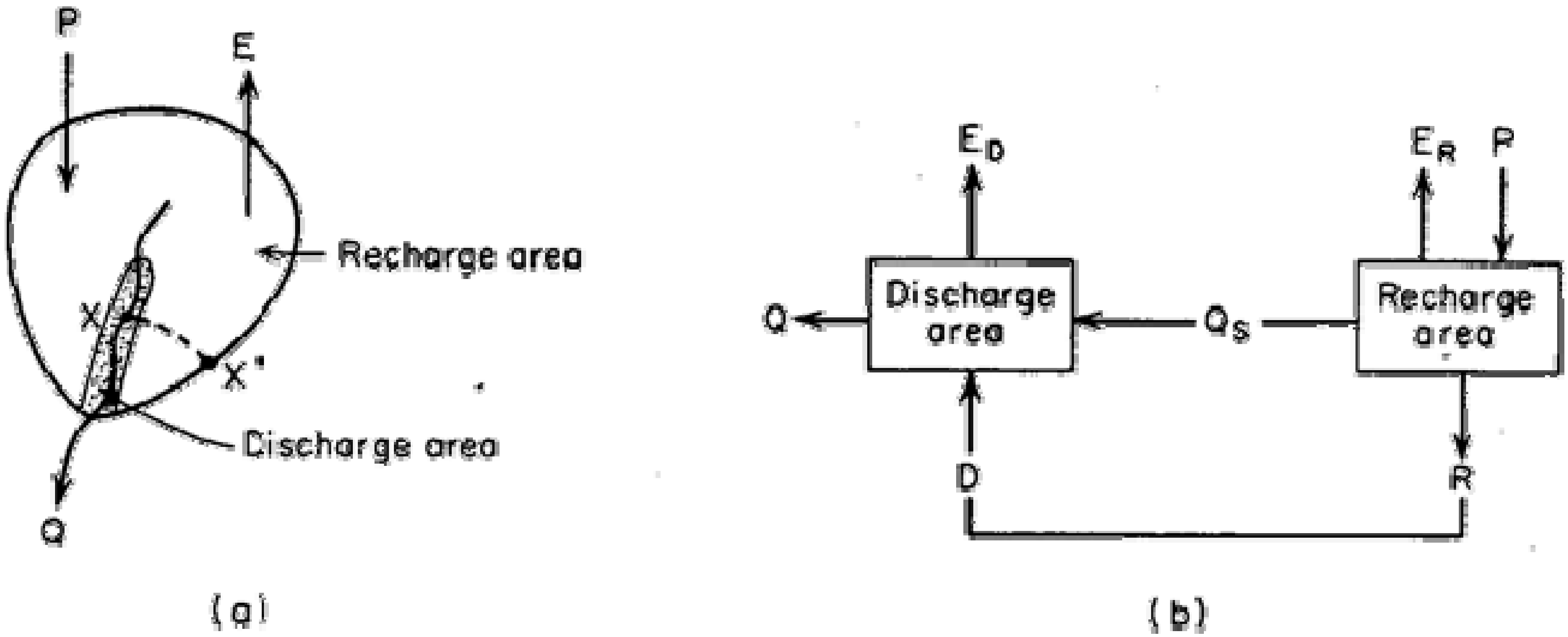
$Sg_2 = \{ g_{ji}, R_{ji} \}$,

where g_{ji}- watershed.

Any watershed g_{ji} for territory may be considered as a part of stream runoff system Sg_2.

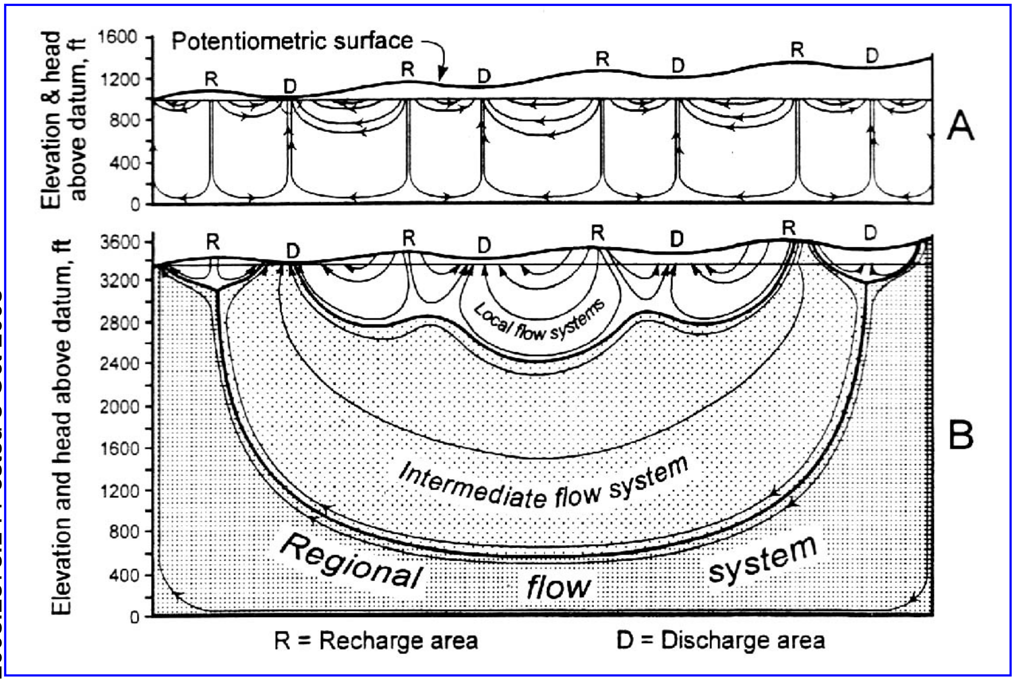
Each of these components may be characterized by matrix of input {Wi}, matrix of output {Qi}, & matrix of states {Hi}.

Watershed water balance

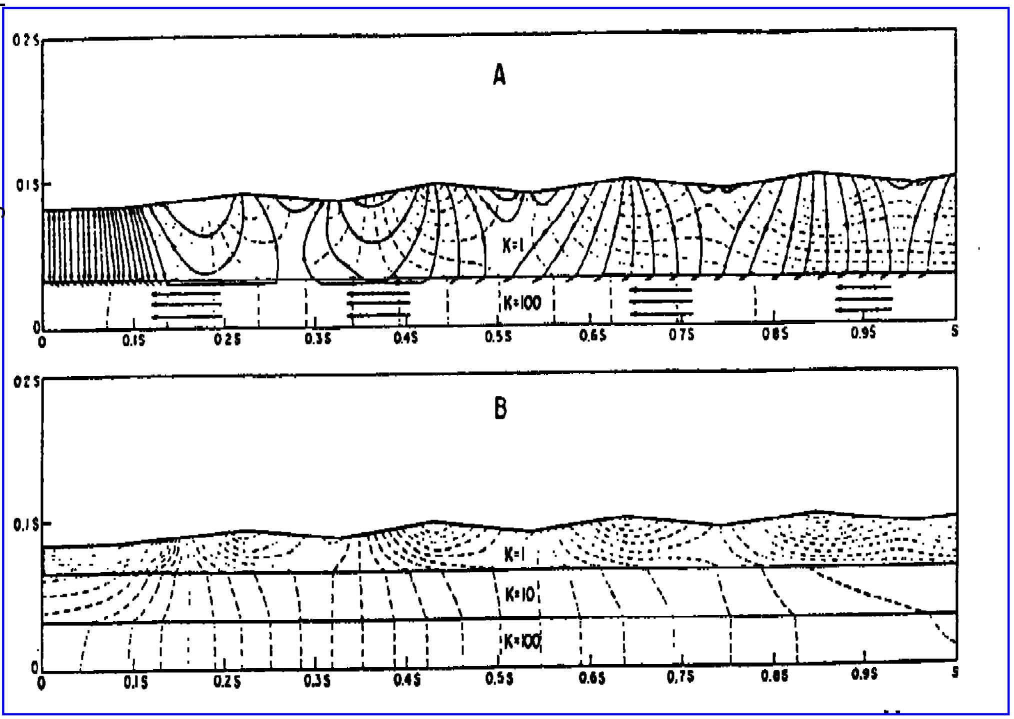


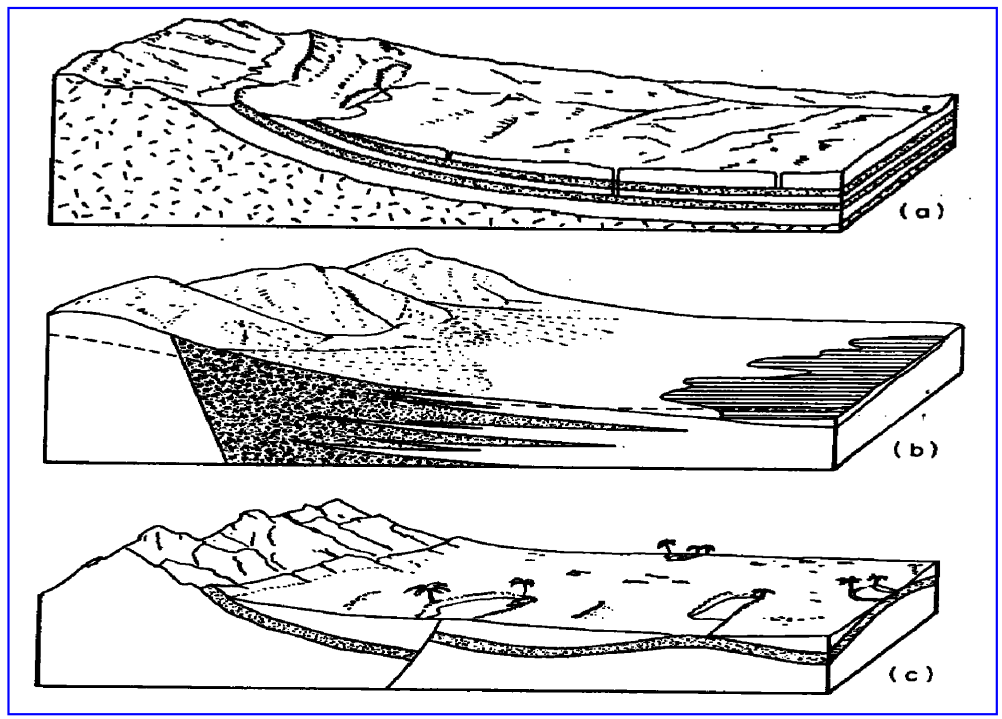
Elements of watershed water balance:
P- precipitation, E- evapotranspiration, Q- runoff, Q_s- the surface water component of average annual runoff, E_R- the average annual evapotranspiration from recharge area, E_D- the average annual evapotranspiration from discharge area, R- the average annual ground water recharge, D- the average annual ground water discharge;
X--X'- cross-section from shown in (b) - quantitative flow net & recharge-discharge profile in a two-dimensional section across the heterogeneous groundwater basin (after Freeze and Cherry, 1979)

Watershed in a landscape

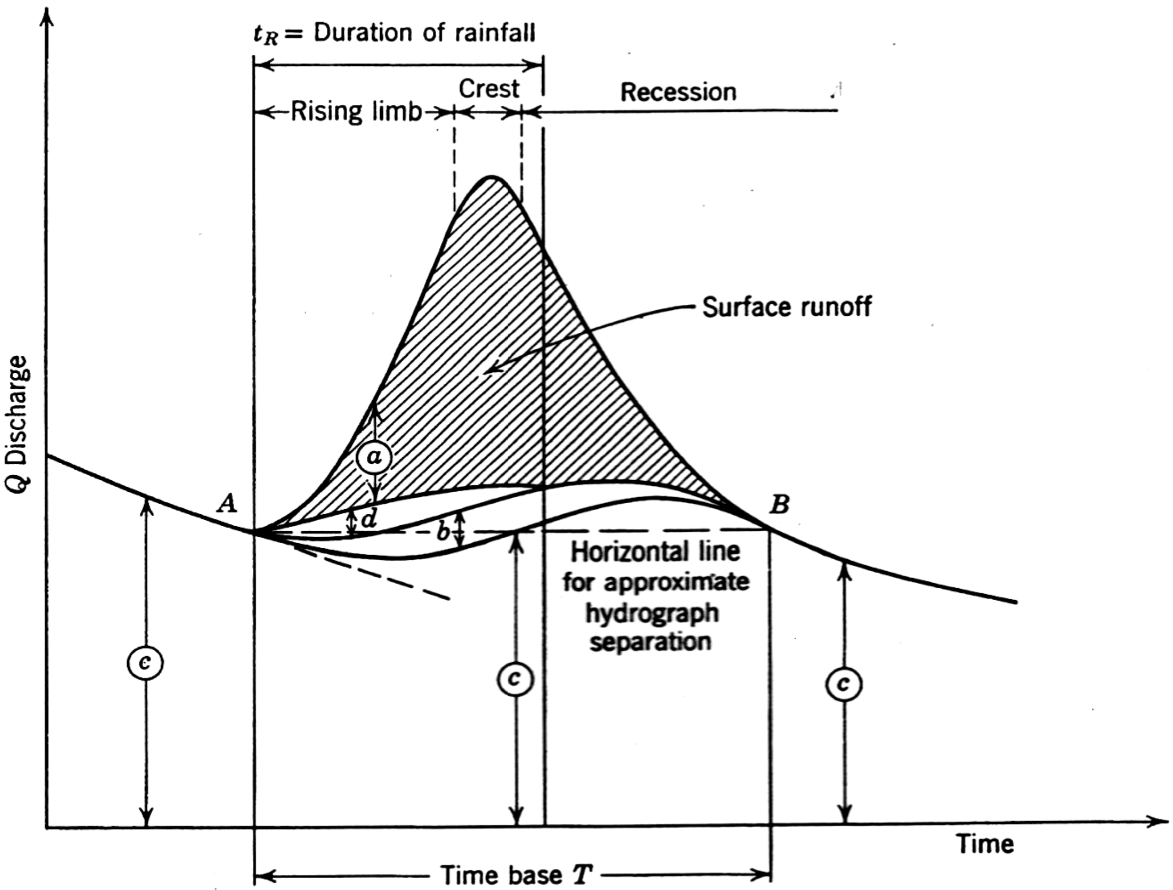


Cross-sections for different hydrogeological settings, showing the influence of stratigraphy & structure on regional aquifer occurrence (after Freeze and Cherry, 1979).





The components of a hydrograph & watershed characteristics



Components of hydrograph (De Wiest, 1967)

The specific hydrologic characteristics used in analysis are:

- average annual stream runoff rate or yield [l/s/sq km or mm/year]

- average rate or yield of minimal monthly stream runoff [l/s/sq km or mm/year]

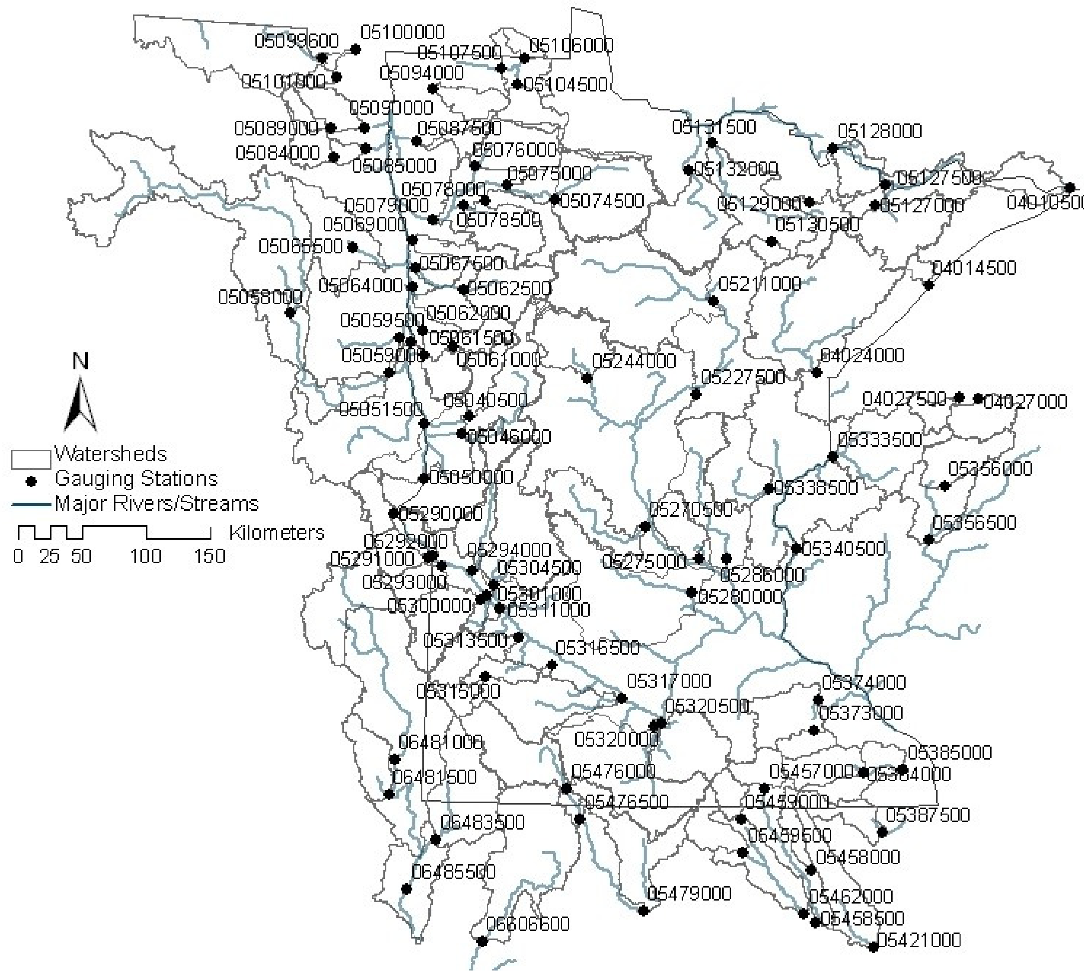
- monthly proportion of annual stream runoff [% or as a parts of 1.0]

Analysis stream runoff in MN for period 1955-1979

Initial matrix:

$Q_{(n*p)}$ or $Q_{(93*14)}$

there are:
n=93 – number of rows or watersheds,
p=14 – number of variables or 12 monthly proportions, February & annual yield



Data

Initial matrix:

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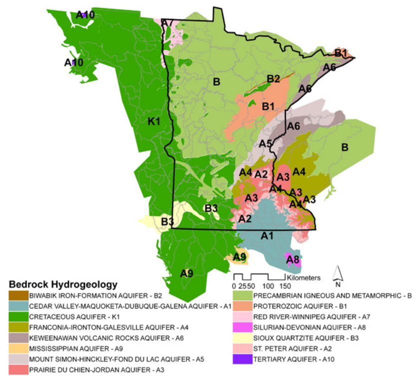
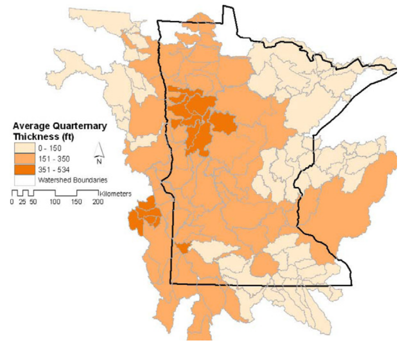
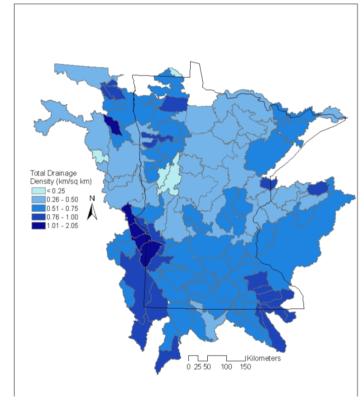
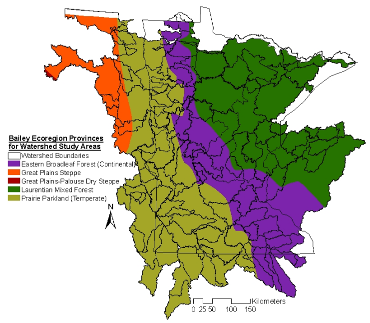
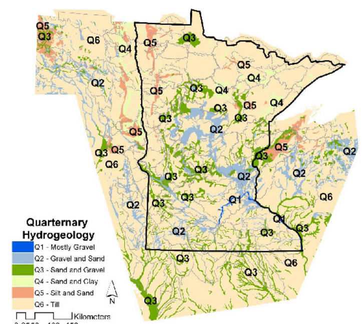
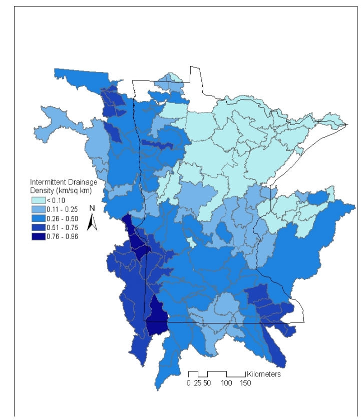


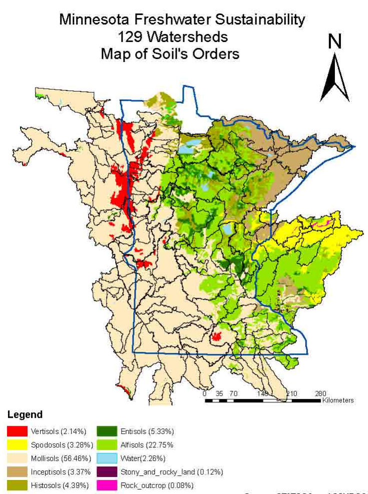


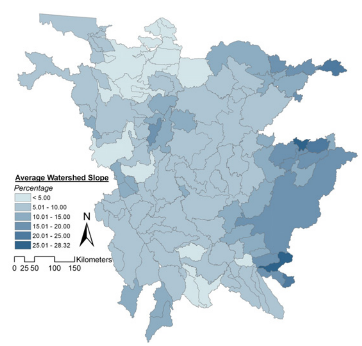


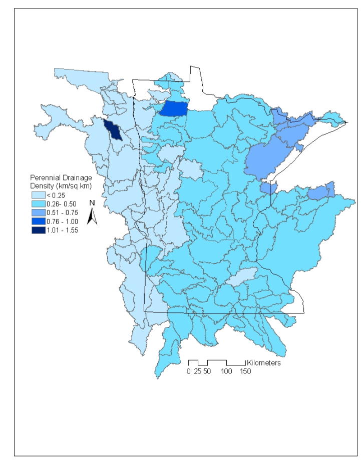












Data & philosophy of analysis

A **factor** is a portion of a quantity, usually an integer or polynomial that, when multiplied by other factors, gives the entire quantity.

The determination of factors is called factorization (or sometimes "factoring"). It is usually desired to break factors down into the smallest possible pieces so that no factor is itself factorable.

Factor analysis allows the determination of common axes influencing sets of independent measured sets. It is "the granddaddy of multivariate techniques (Gould 1996, pp. 42-43) and was invented by Spearman.

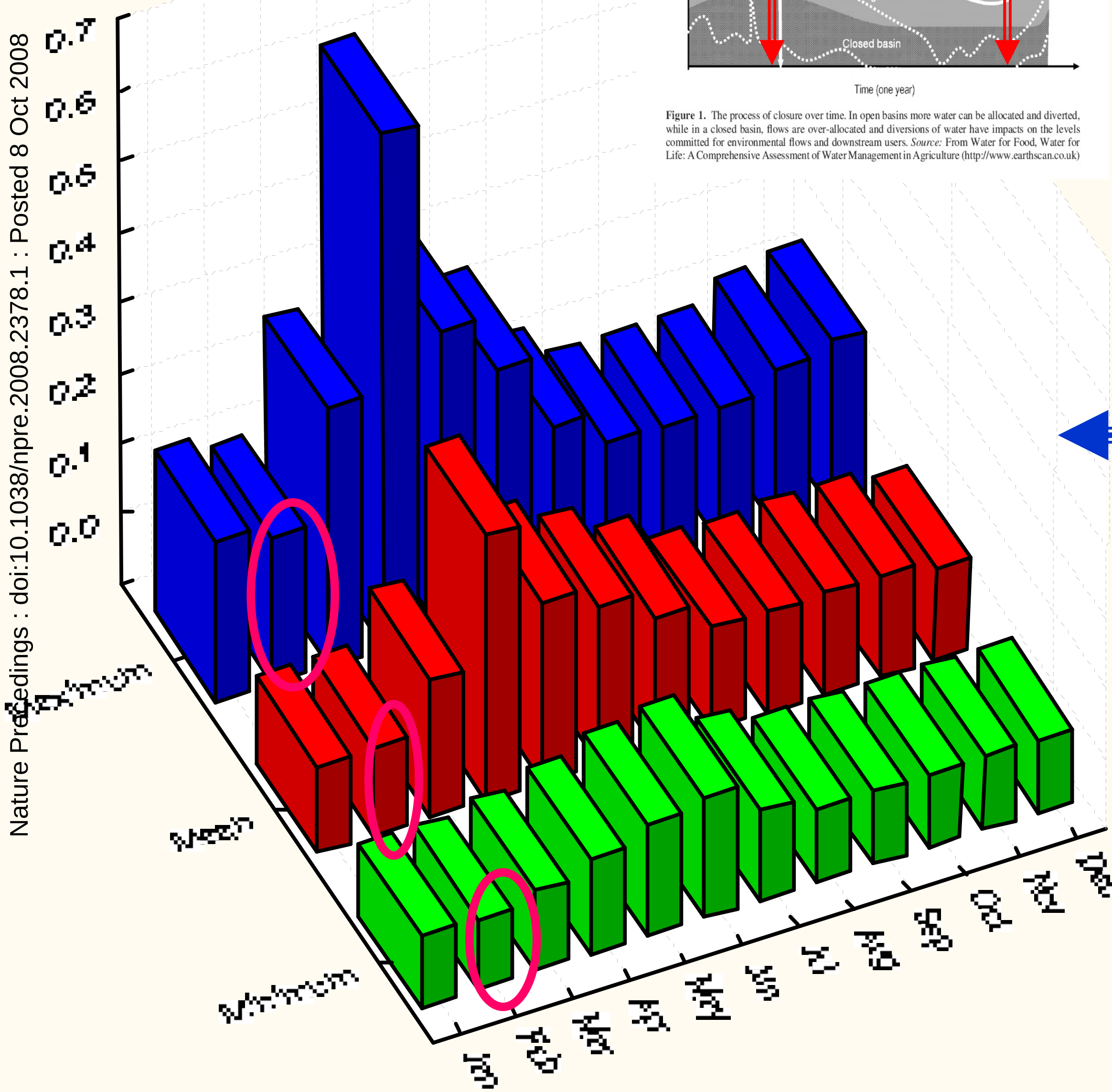
Multivariate analysis is the simultaneous statistical consideration of relationships among many measured properties of a given system (Gould 1996, p. 42;).

The main applications of factor analytic techniques are:

- (1) to *reduce* the number of variables and
- (2) to *detect structure* in the relationships between variables, that is to *classify variables*.

(From: Wolfram *MathWorld*)

3D Sequential Graph of Monthly Proportions



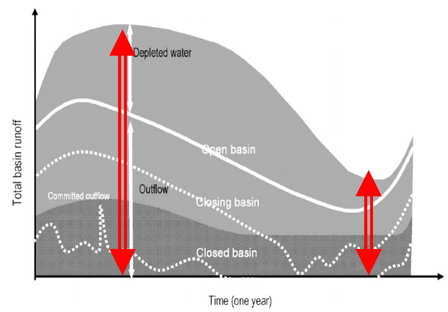
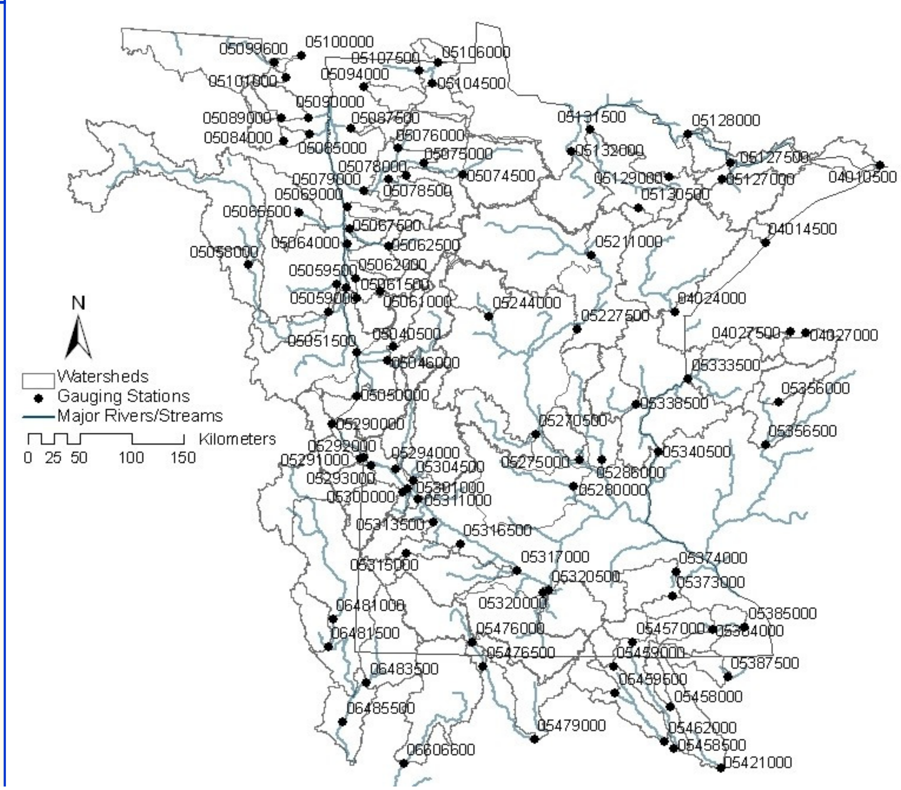
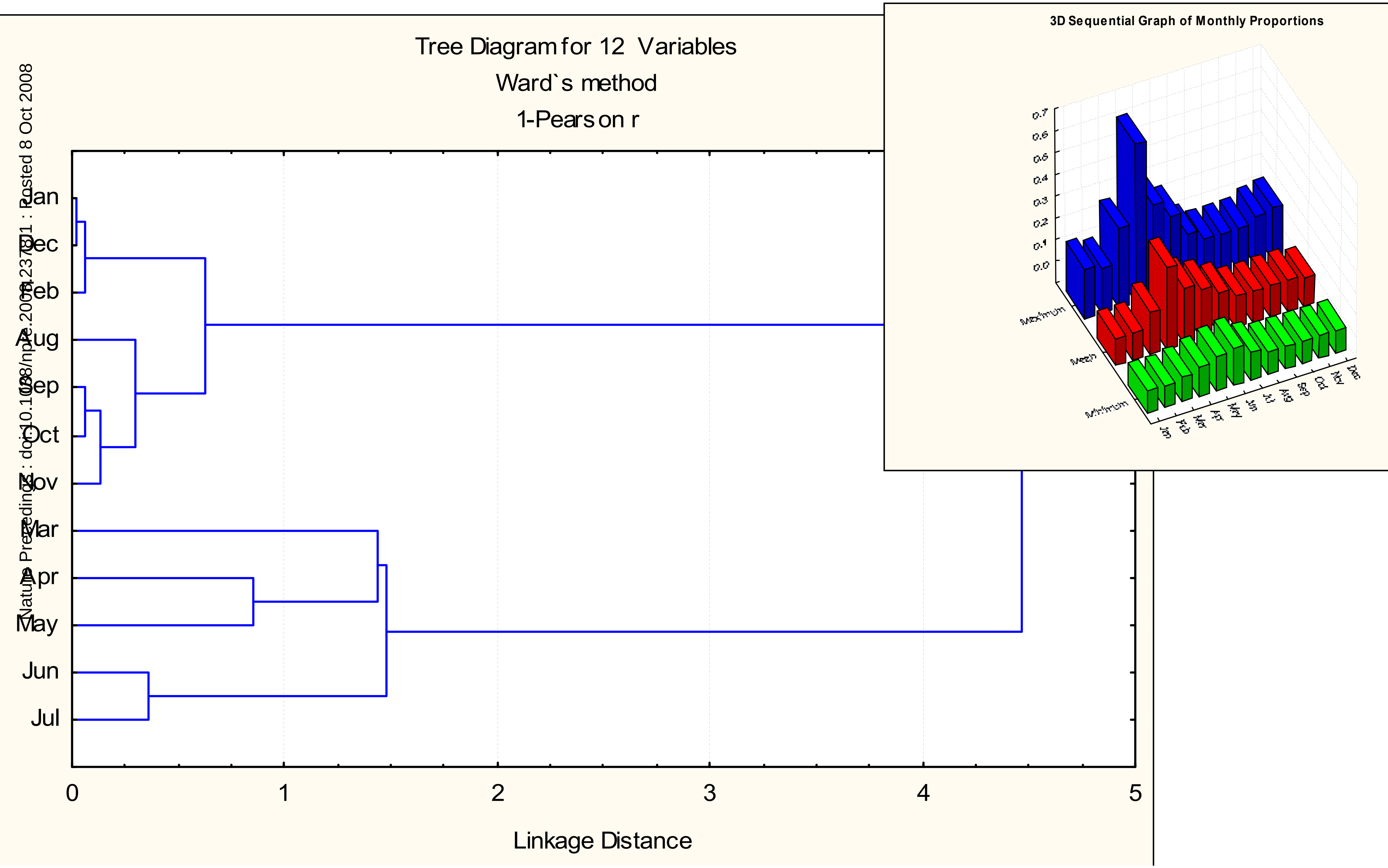


Figure 1. The process of closure over time. In open basins more water can be allocated and diverted, while in a closed basin, flows are over-allocated and diversions of water have impacts on the levels committed for environmental flows and downstream users. *Source:* From Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture (http://www.earthscan.co.uk)

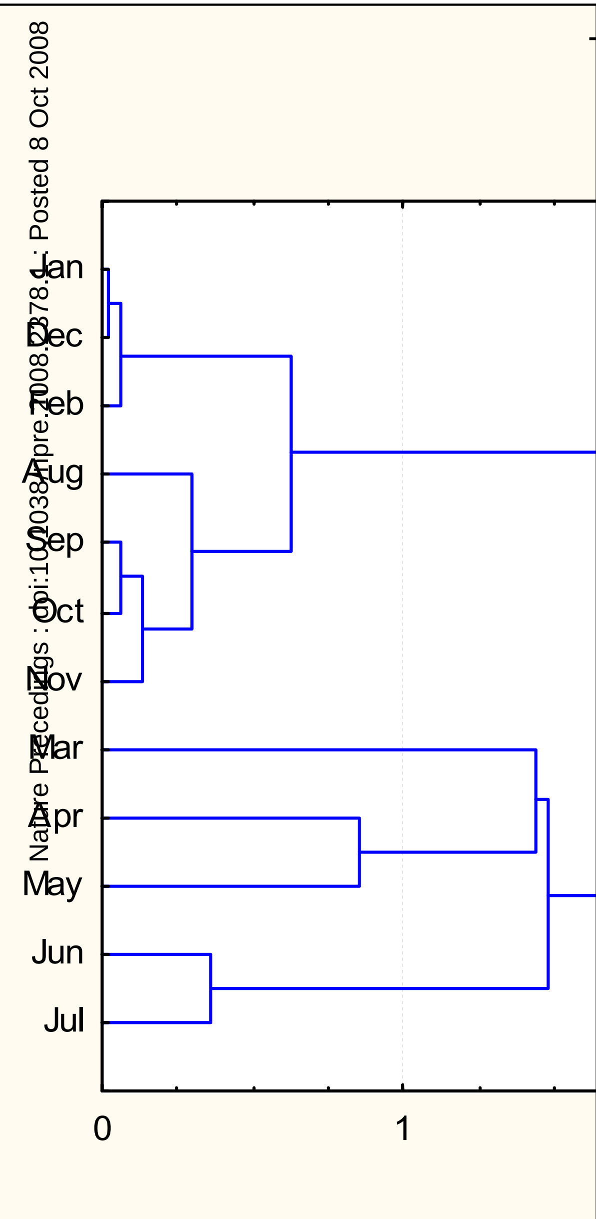
The "hydrograph" of streamflow in MN

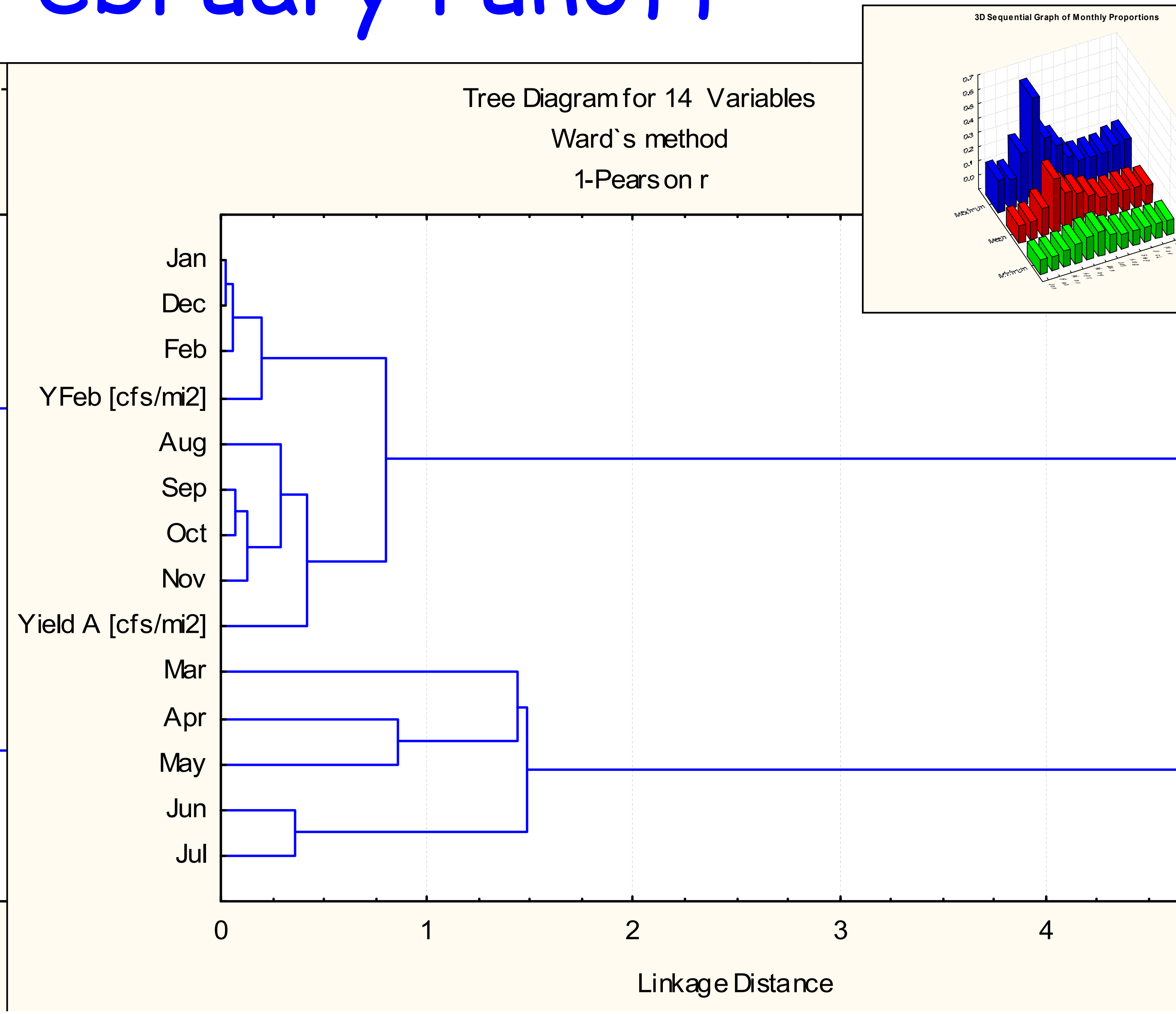


The monthly streamflow in MN as a cluster tree



Cluster trees for annual & February runoff





The monthly runoff in MN as a cluster tree & Factor Loading

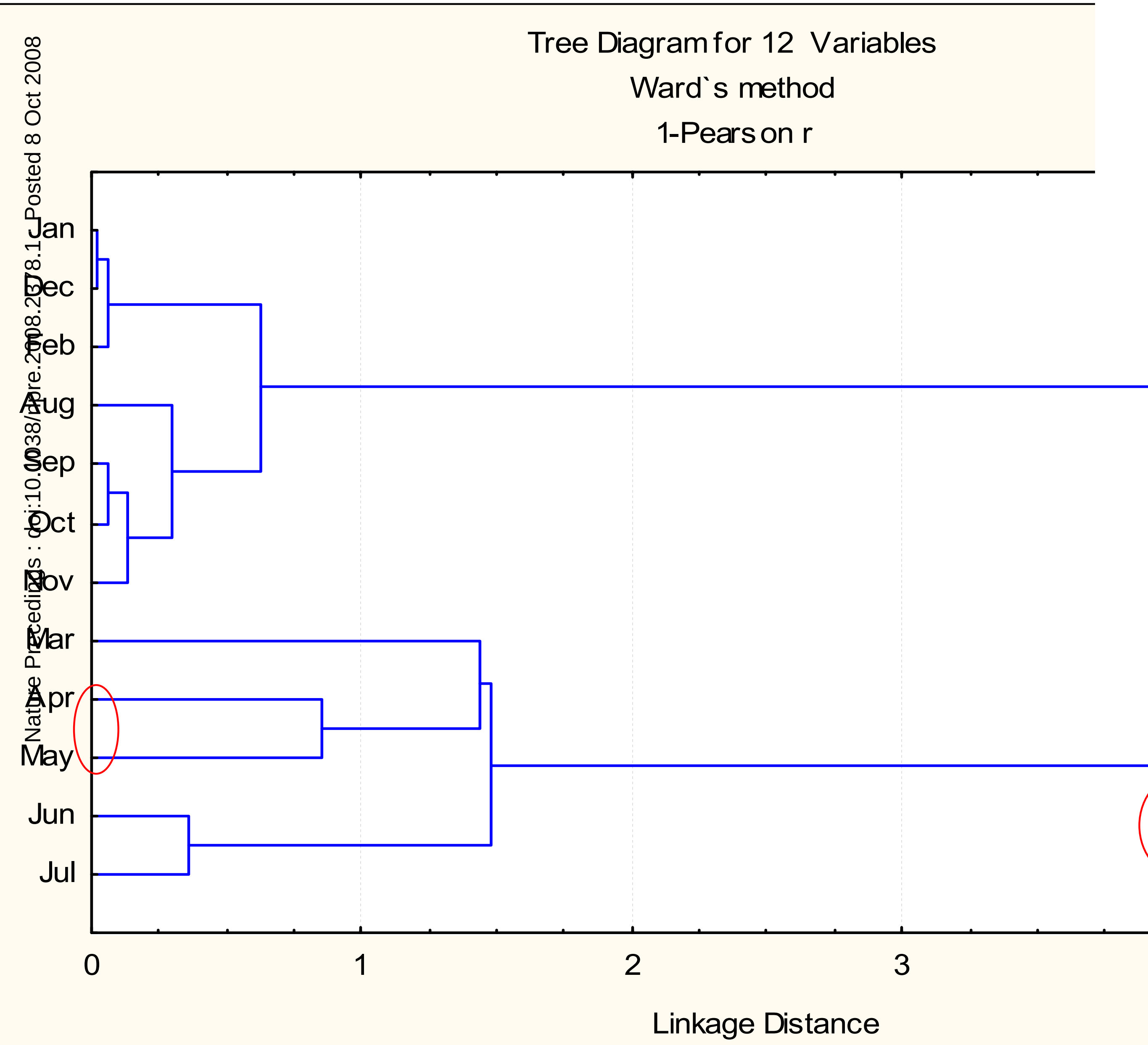
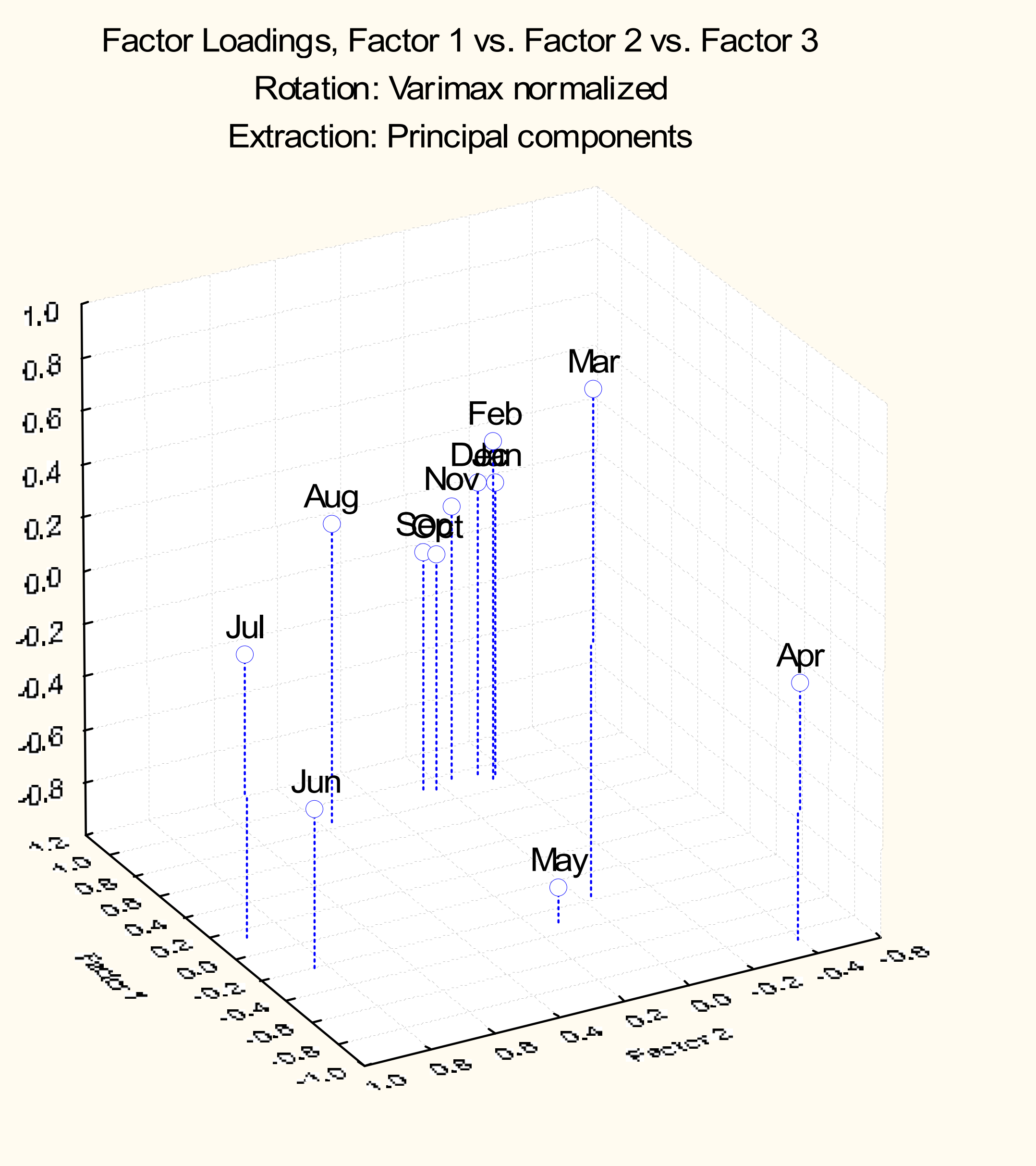


Table of Factor Loading of monthly proportion for 1955-79

	Factor 1	Factor 2	Factor 3
Nov	**0.96**		
Dec	**0.95**		
Sep	**0.92**		
Jan	**0.91**		
Oct	**0.90**		
Feb	**0.88**		0.28
Aug	**0.84**	0.37	
Jul		**0.91**	
Mar			**0.90**
Jun		**0.84**	-0.40
May	-0.30		**-0.87**
Apr	**-0.87**	-0.39	
Expl.Var	6.72	1.92	1.87
Prp.Totl	0.56	0.16	0.16

The monthly runoff in MN as Factor Loading structure



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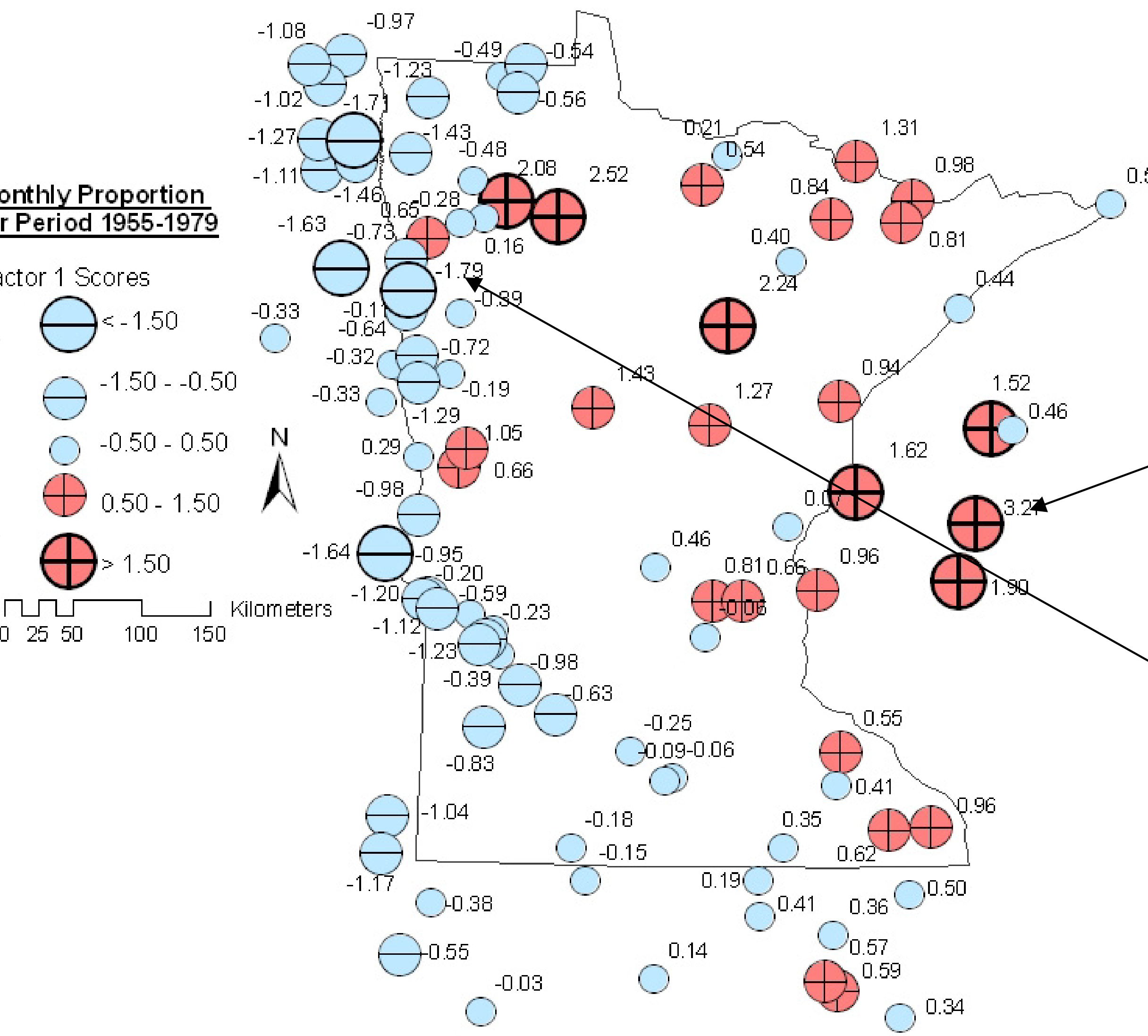
Factor 1 Scores of watersheds in MN



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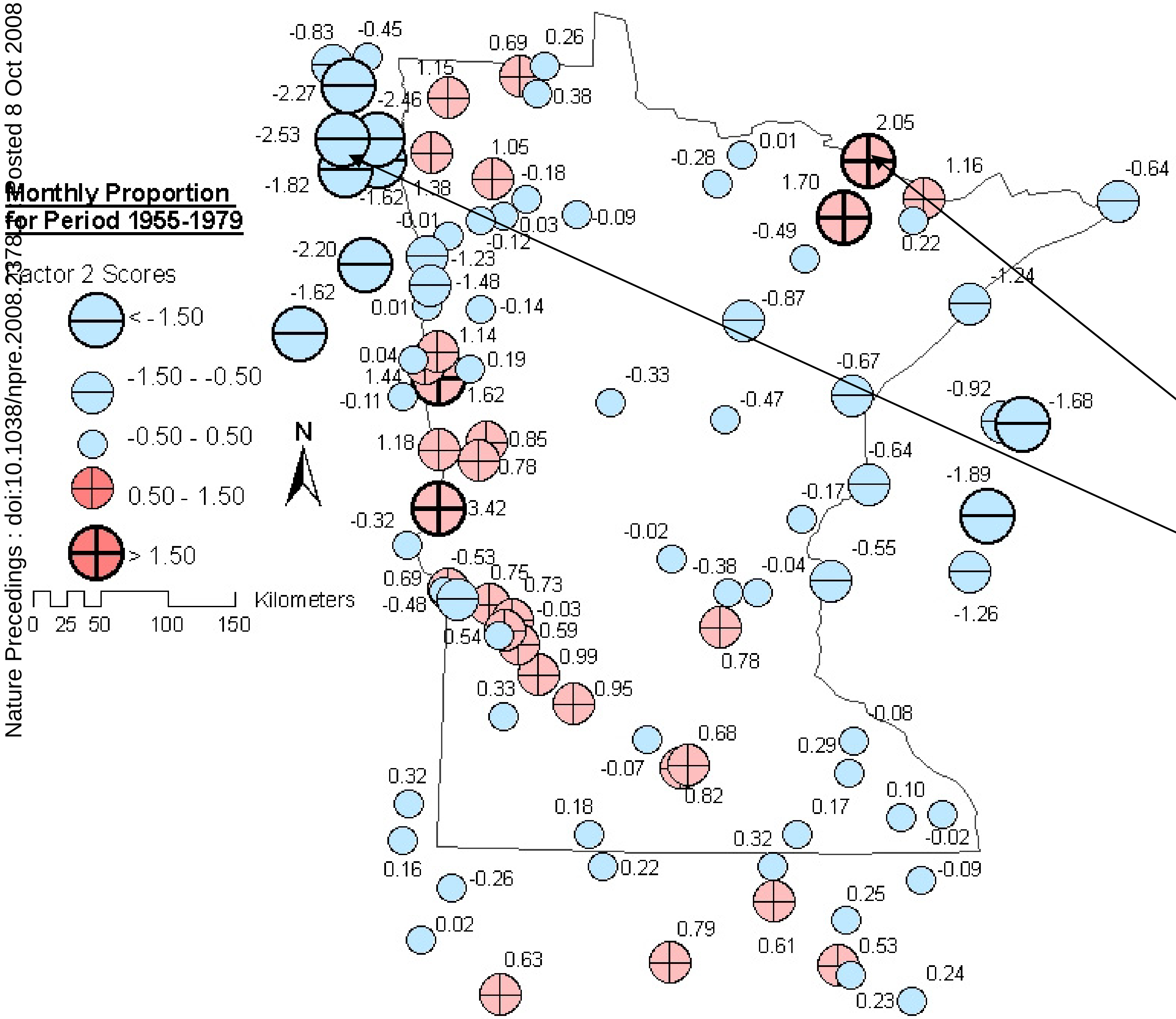
Factor 2 Scores of watersheds in MN



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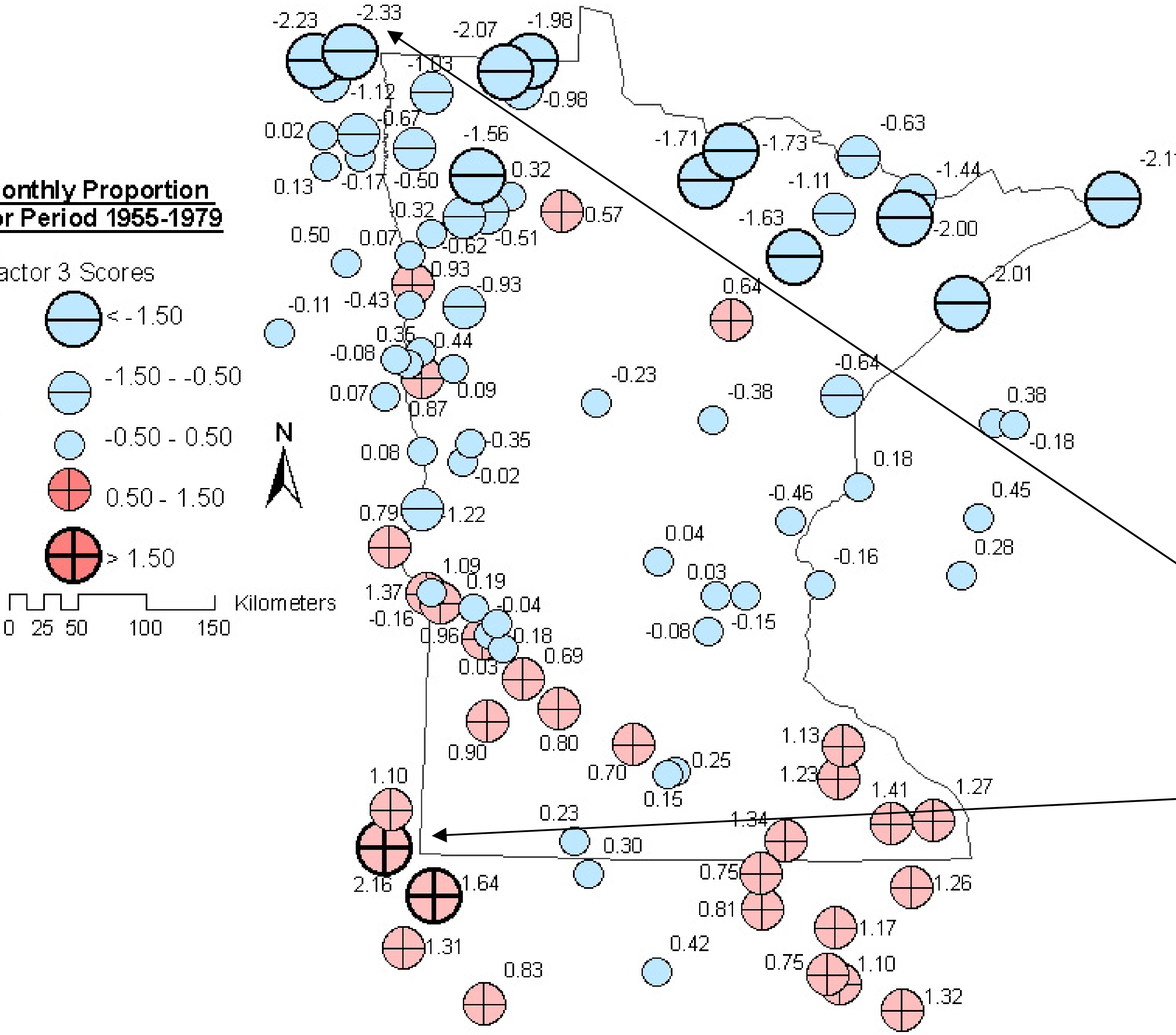
Factor 3 Scores of watersheds in MN



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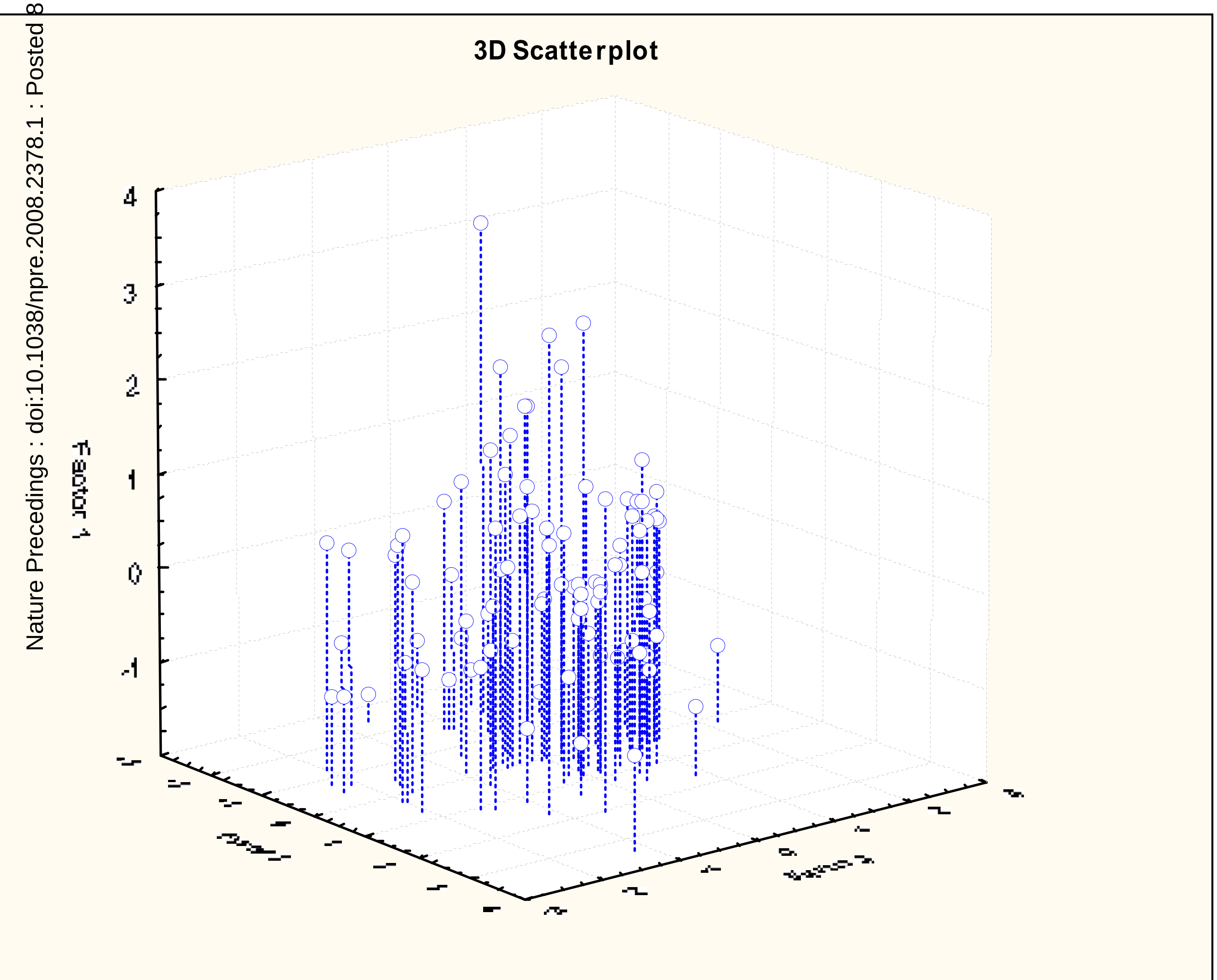
Factor Scores of watersheds in coordinates of streamflow monthly proportions in MN



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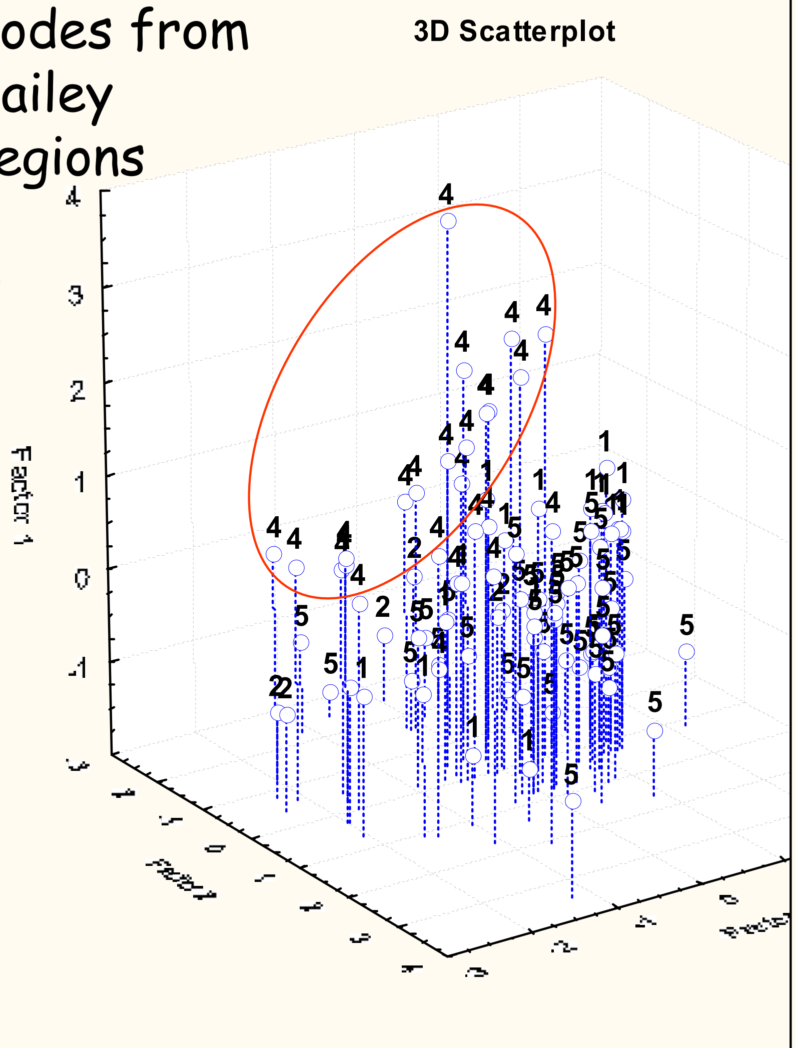
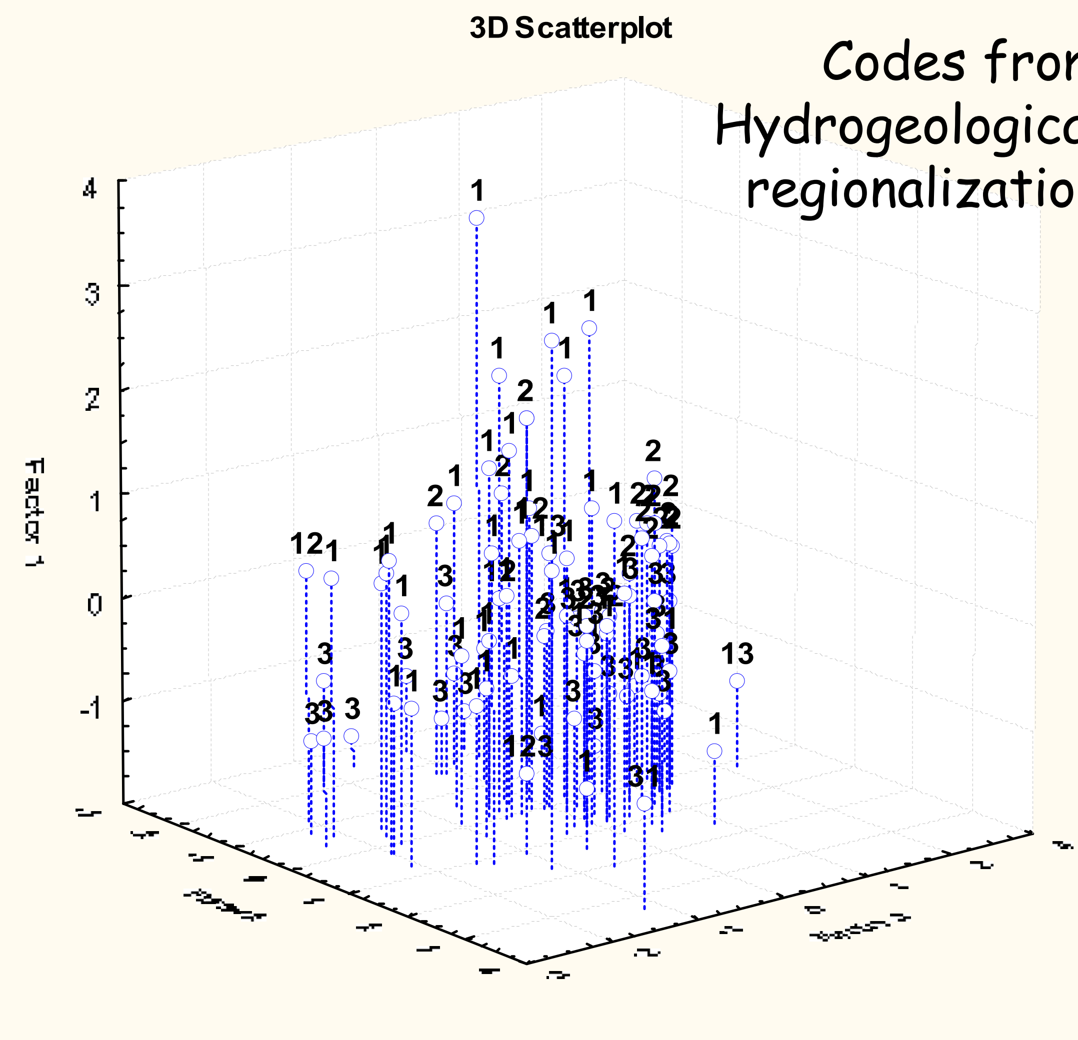
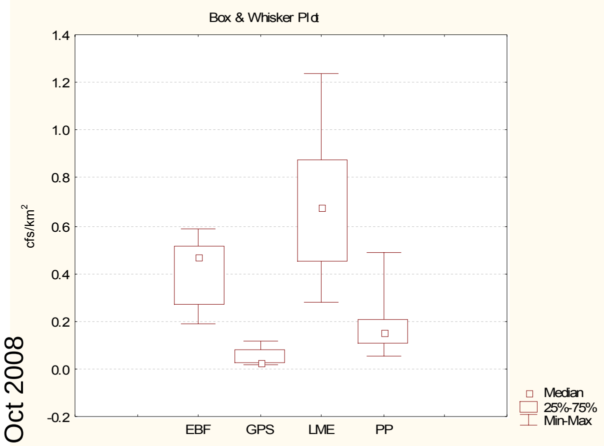
Factor Scores of watersheds in coordinates of streamflow monthly proportions in MN

Codes from Bailey regions

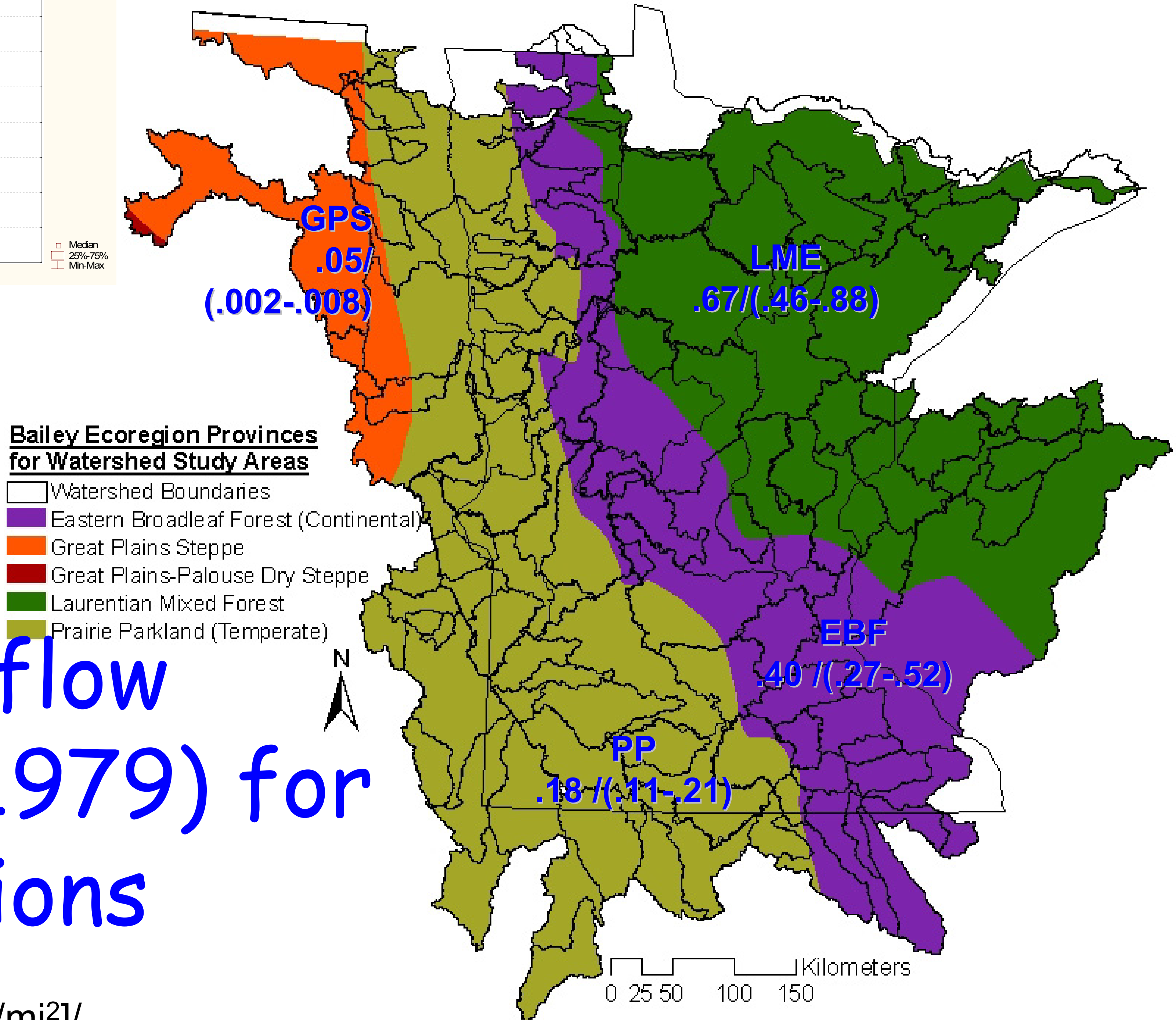


Codes from Hydrogeological regionalization

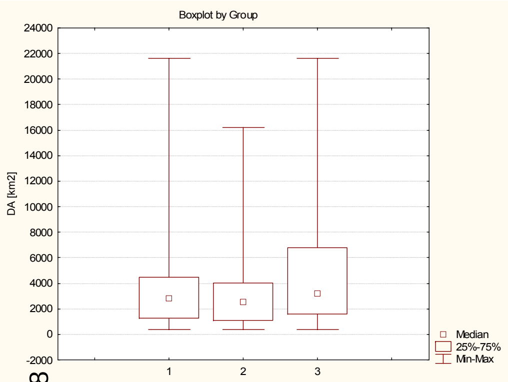


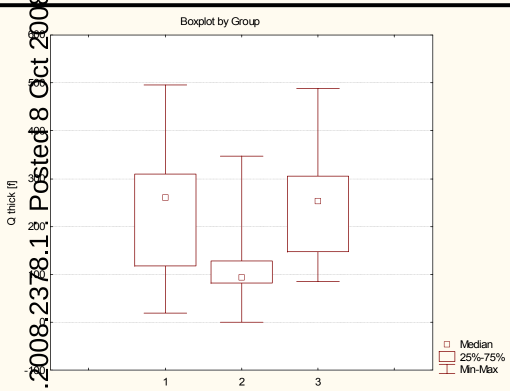


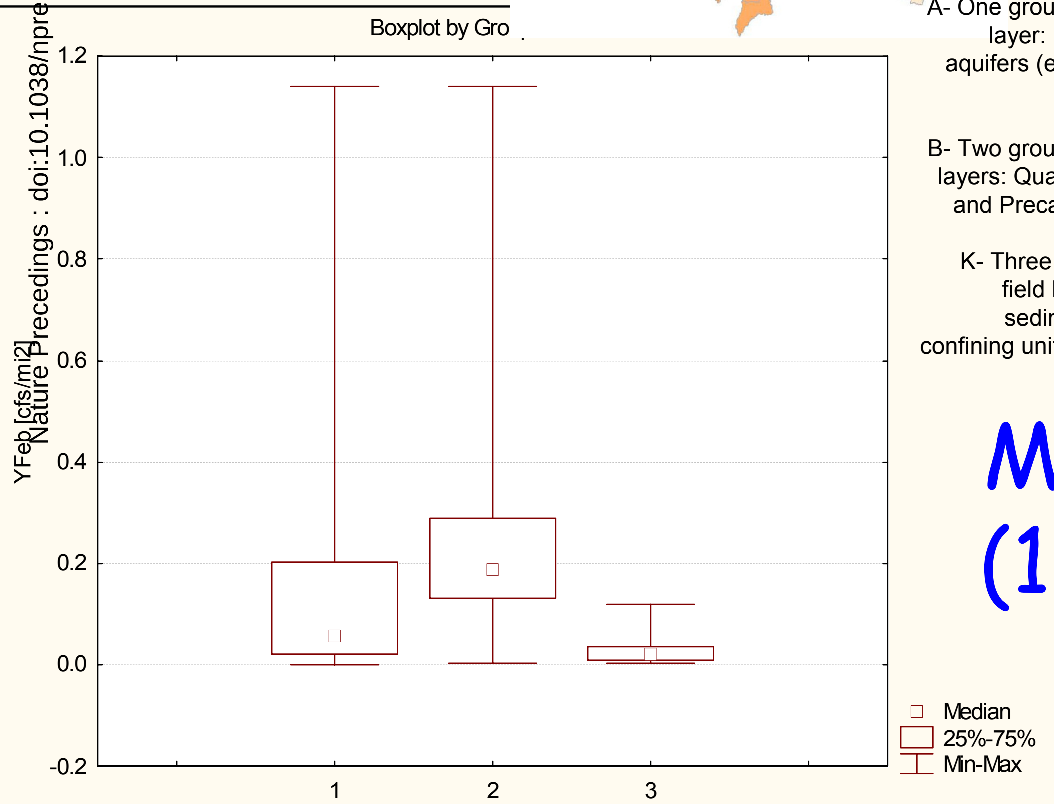
Mean annual streamflow (1955-1979) for Ecoregions

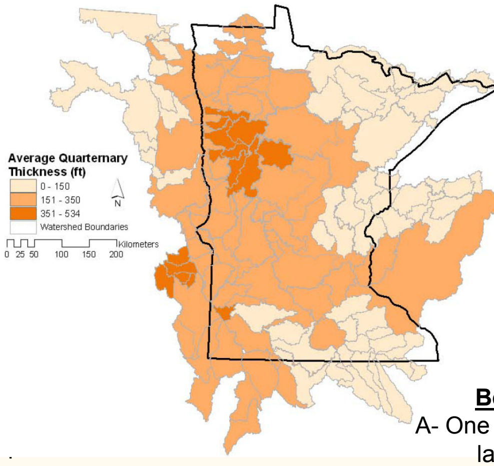


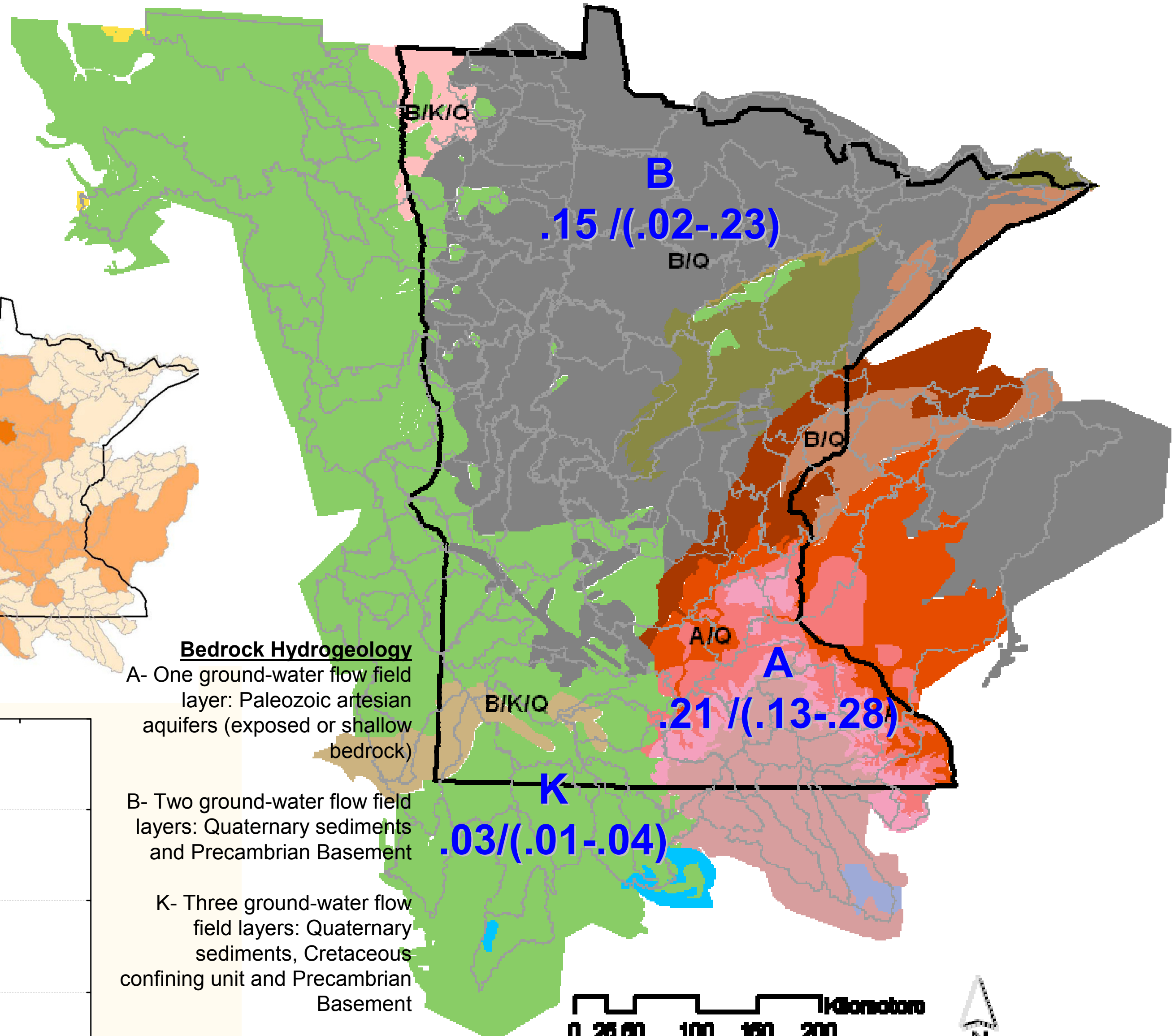
Numbers show:
average yield [cfs/mi²]/
(quartile lower- quartile upper)







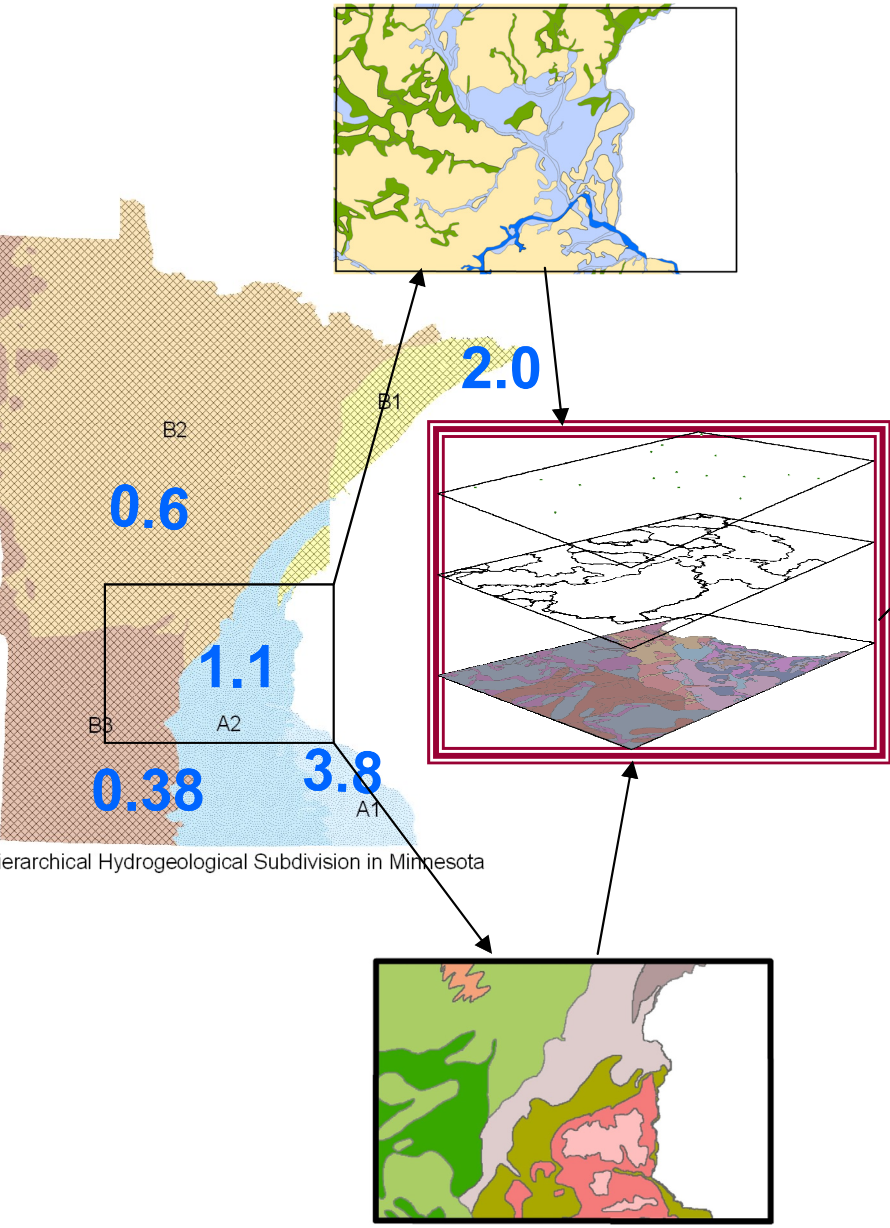




Mean February streamflow (1955-1979) for HGregions

Numbers show:
mean yield [cfs/mi²]/
(quartile lower- quartile upper)

Two maps with GW recharge in MN



Initial matrix:

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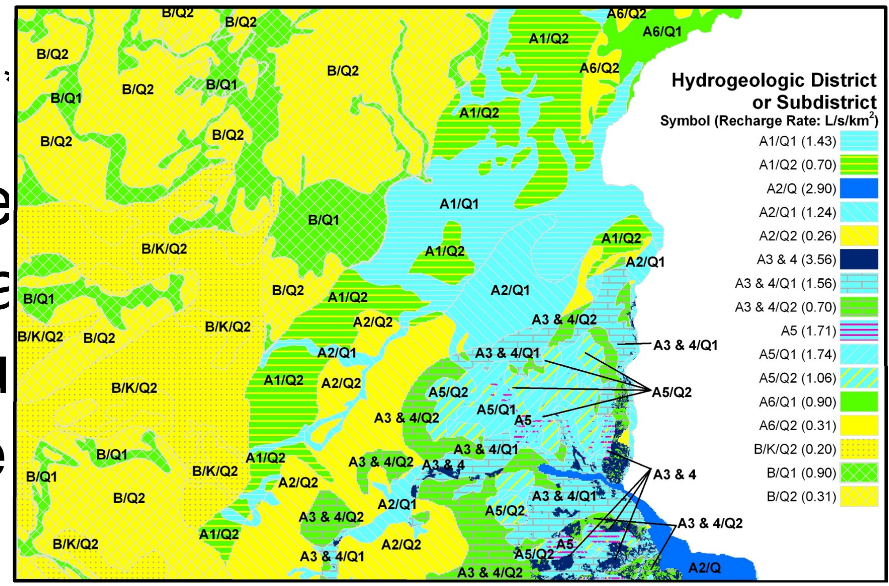
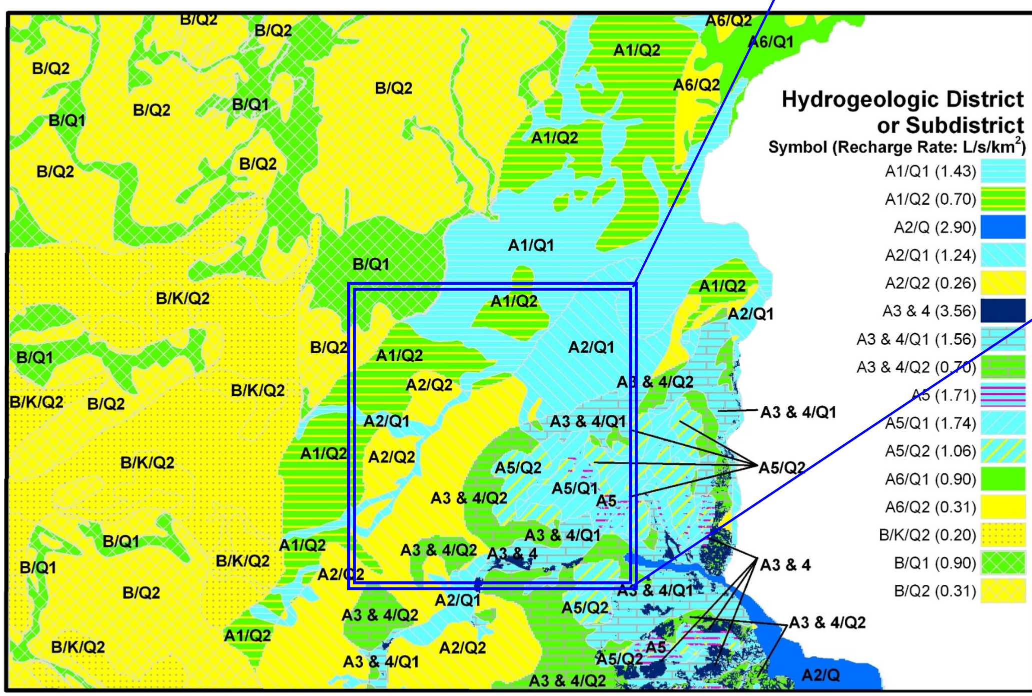
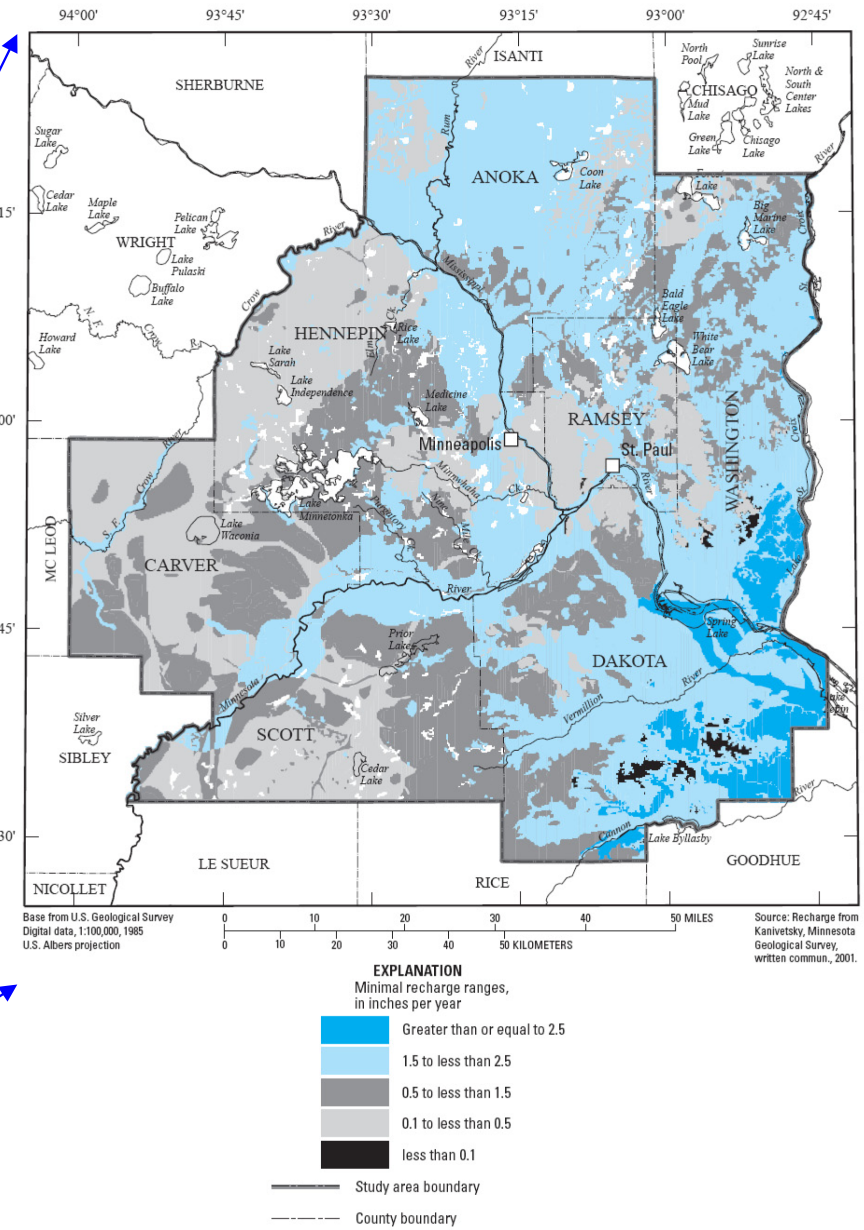


Minimal ground-water recharge based on statistical analyses of watershed characteristics for Eastern Central Minnesota

Two maps with GW recharge





Minimal ground-water recharge based on statistical analyses of watershed characteristics in the TC metropolitan study area, MN

Maps & regime – units & boundaries

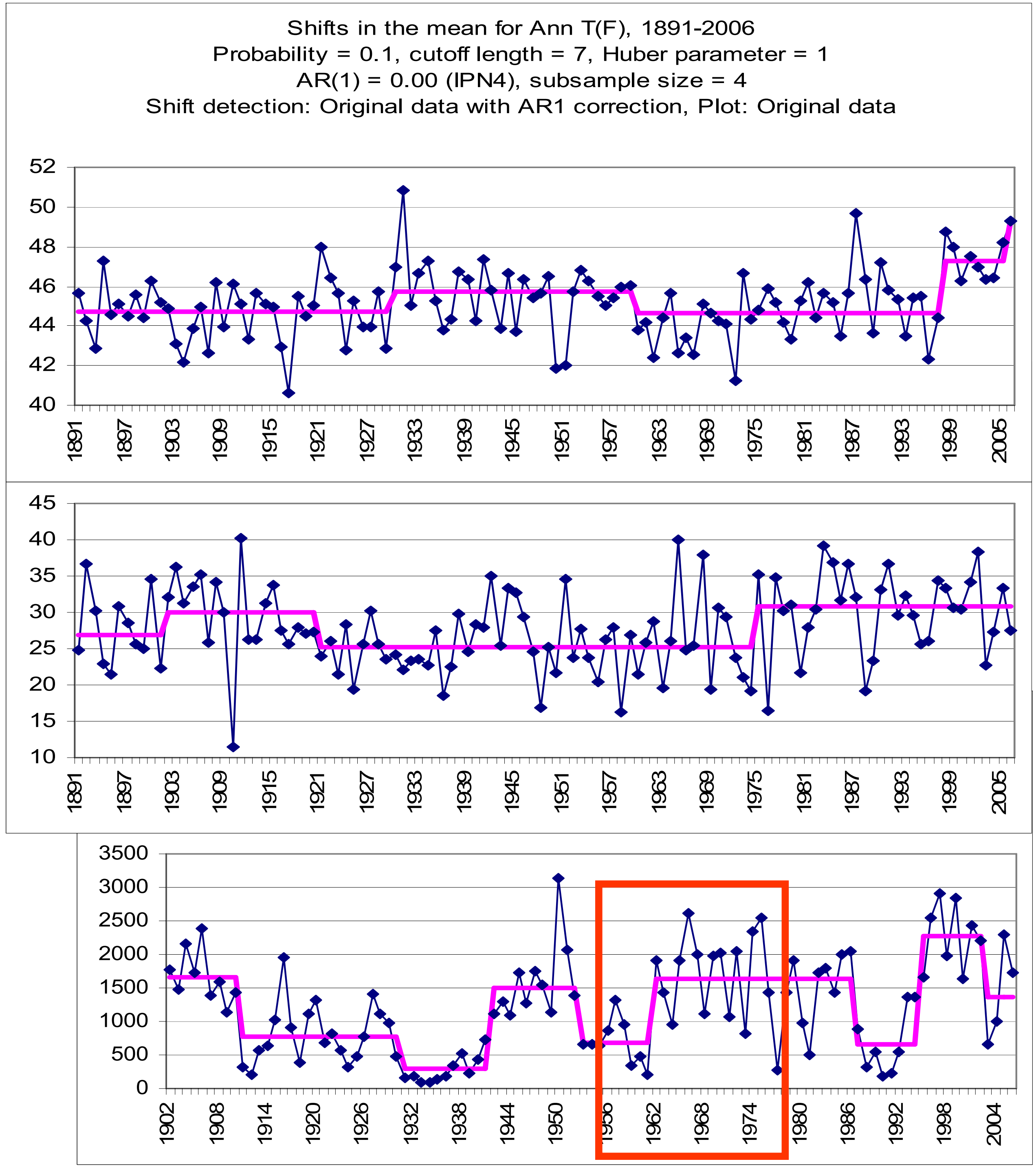
- Groups of watersheds recognized by mutual landscape properties with statistical proven influence on hydrologic characteristics provide base for regionalization
- The units on a map reflect regionalization with average hydrologic characteristics for those kind of groups or its range
- The values of characteristics on the map reflect the interval of observation (presented case 1955-1979) & have to be placed in long time perspective

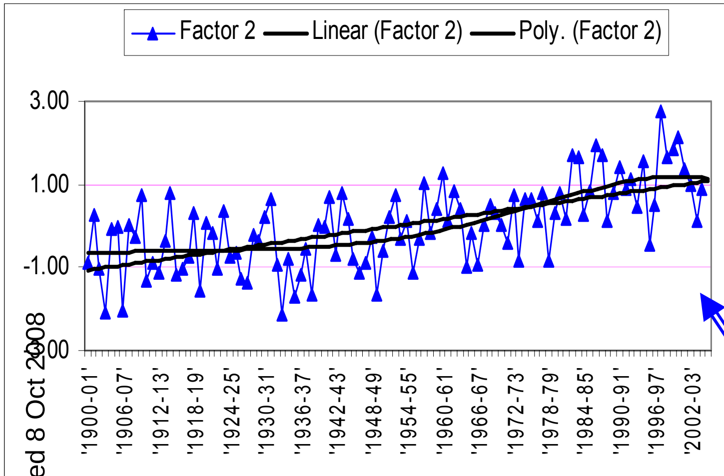
Regime for long time interval

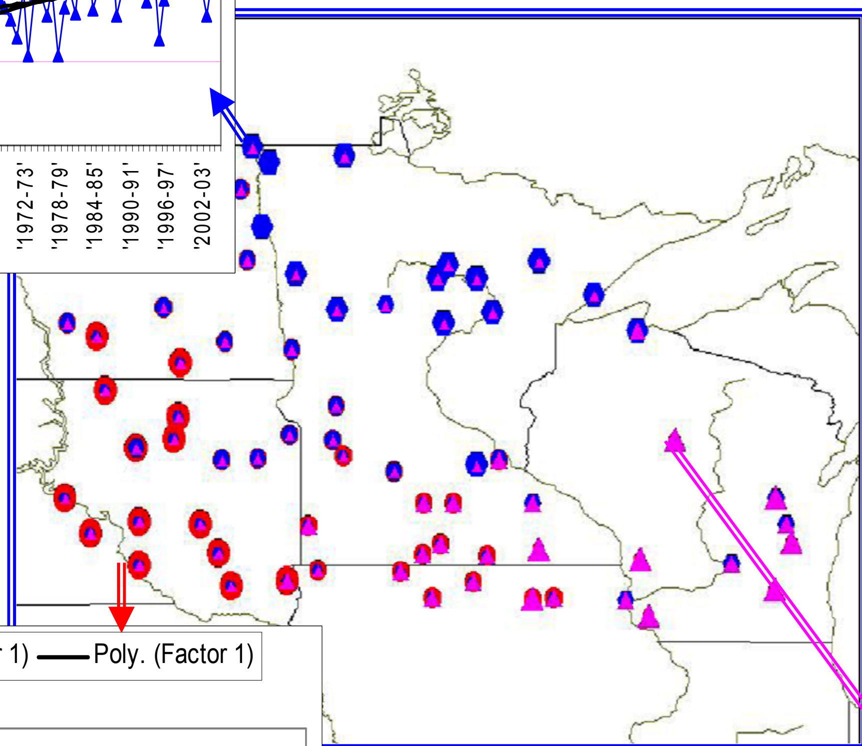
Air temperature (Minneapolis)

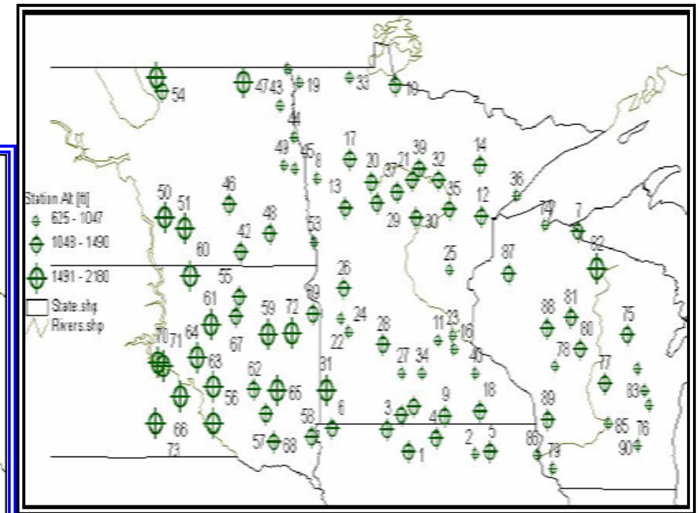
Precipitation (Minneapolis)

Streamflow (Red Lake River)

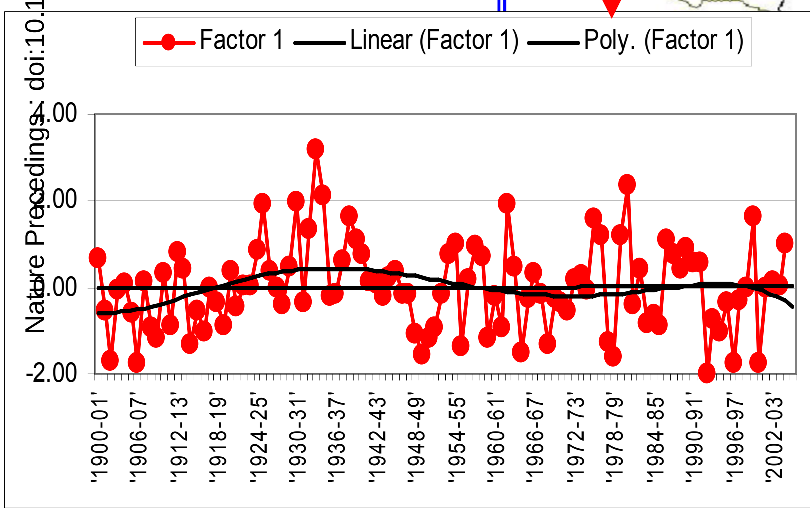


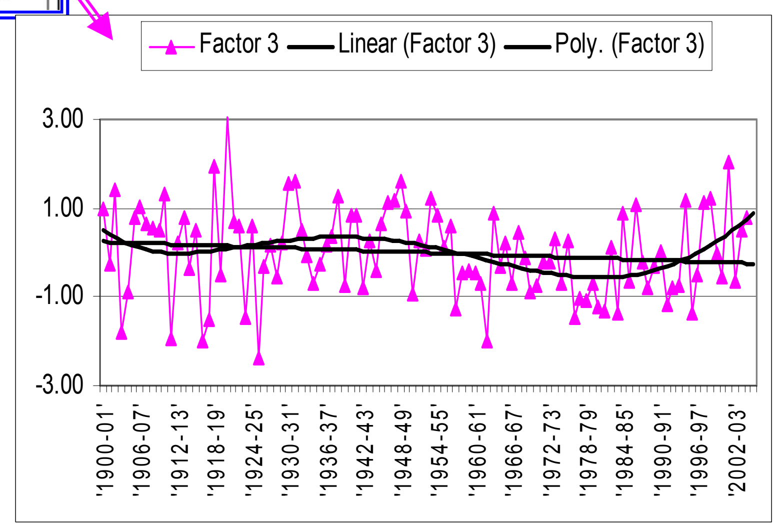






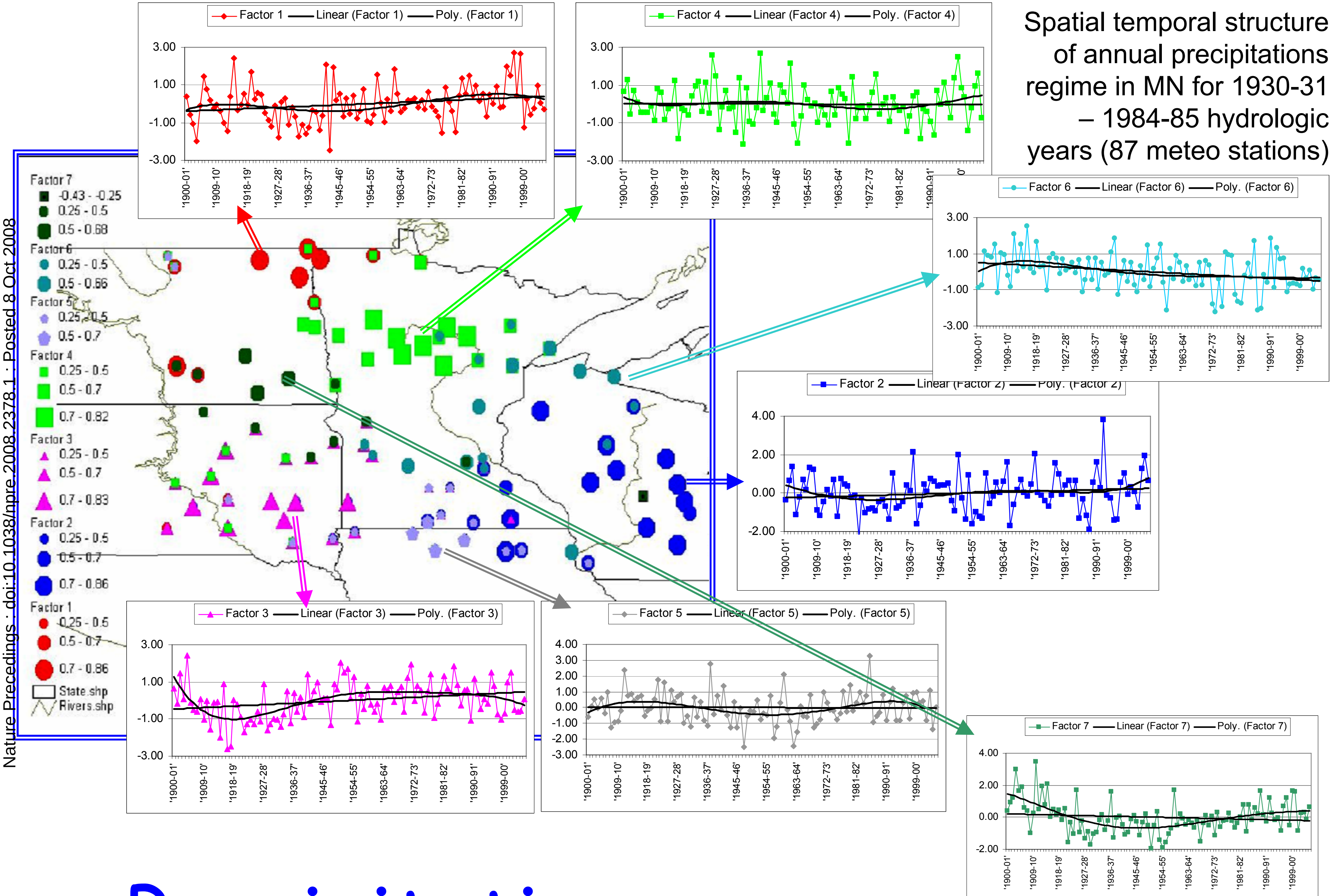
Spatial temporal structure of annual air temperature regime in MN for 1900-01 – 2004-05 hydrologic years (70 meteo stations). The arrows point from the stations with highest Factor Loading to the corresponding chart of Factor Scores



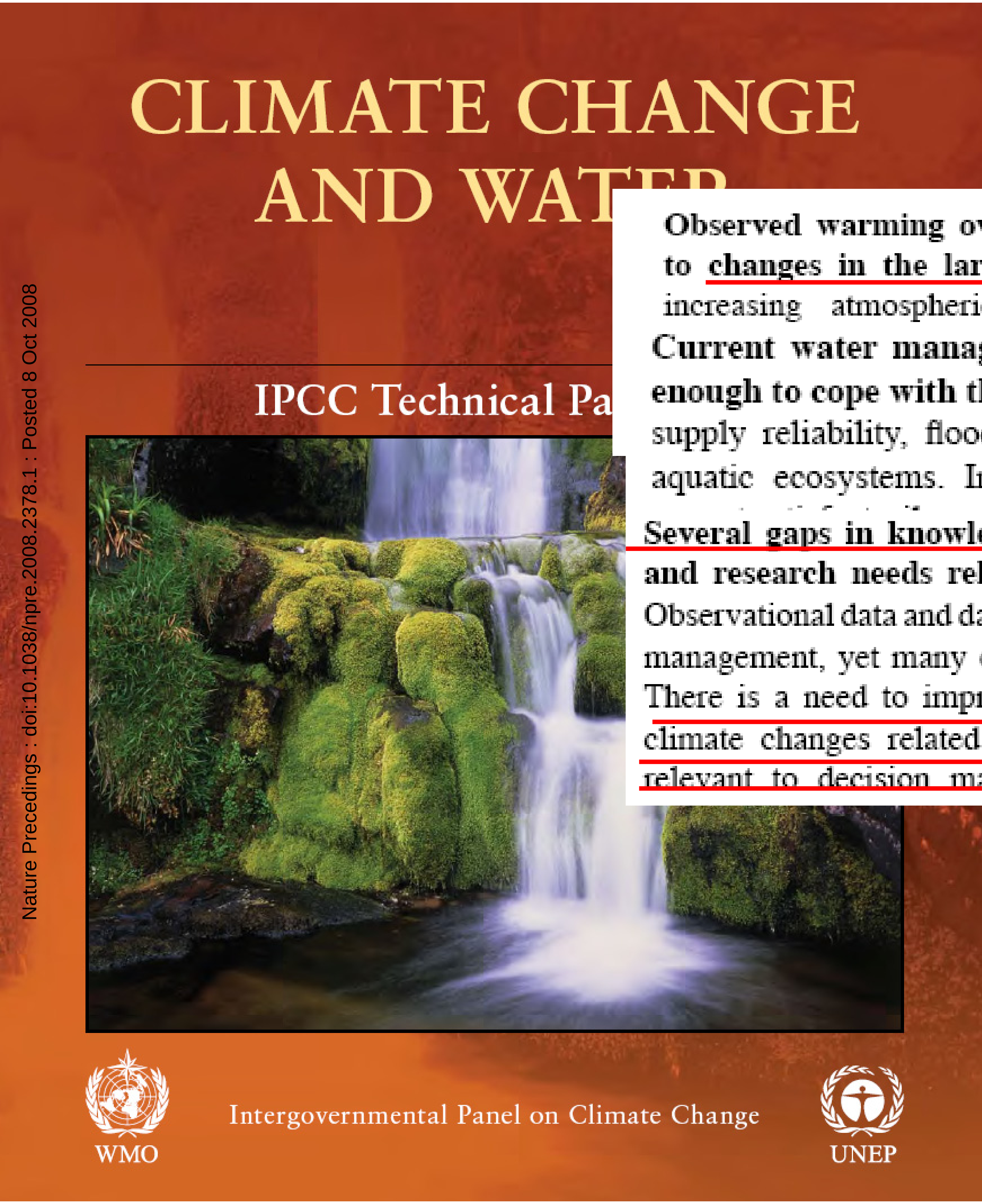


Air temperature

Spatial temporal structure of annual precipitations regime in MN for 1930-31 – 1984-85 hydrologic years (87 meteo stations)



Precipitation



Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content; changing

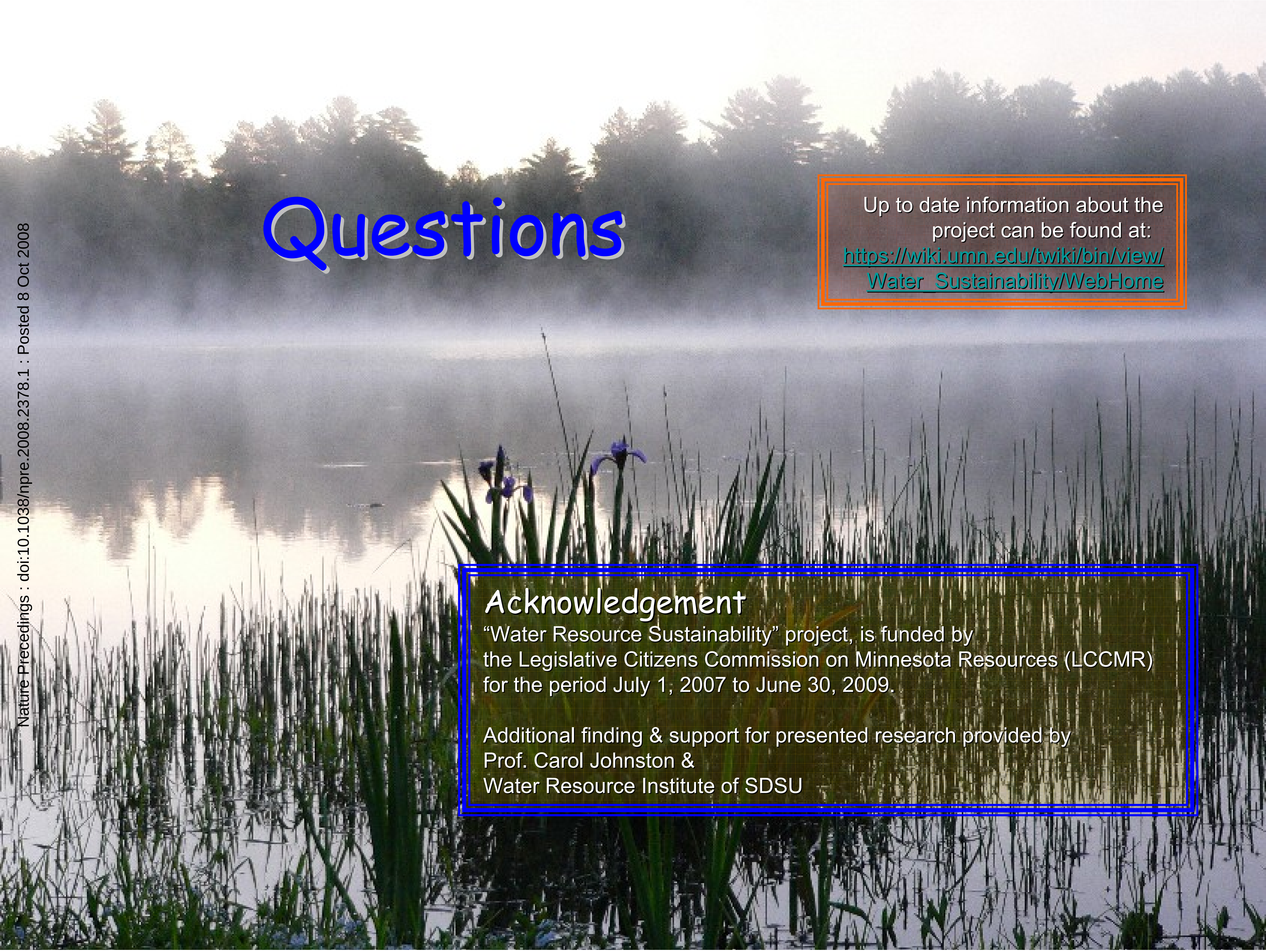
Current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In many locations, water management

Several gaps in knowledge exist in terms of observations and research needs related to climate change and water. Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking. There is a need to improve understanding and modelling of climate changes related to the hydrological cycle at scales relevant to decision making. Information about the water-

From Reports' conclusions

For discussion

- Watershed as hydrological object has a time-spatial scaled structure of interaction (straight & feedback connections) with other components of landscape
- System model (cyber model) of landscape allows to formulate research tasks, develop methods of analysis, create databases, interpret results & present they as a map
- For results of analysis for MN number of factor's axis create seasonal characteristic space dimensions & distribution of watersheds in this space depends upon its hydrologic characteristics
- Map of water resources reflect structure of connection in landscape & statistical proven boundaries
- Atlas for region fully represents scaled diversity of hydrological time-spatial structure



Questions

Up to date information about the project can be found at:
https://wiki.umn.edu/twiki/bin/view/Water_Sustainability/WebHome

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