QUANTITATIVE MAPPING OF RECHARGE/DISCHARGE FOR THE PLANNING OF GROUND-WATER SUSTAINABILITY IN MINNESOTA

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WATER SUSTAINABILITY CONCEPT

- ***IS***

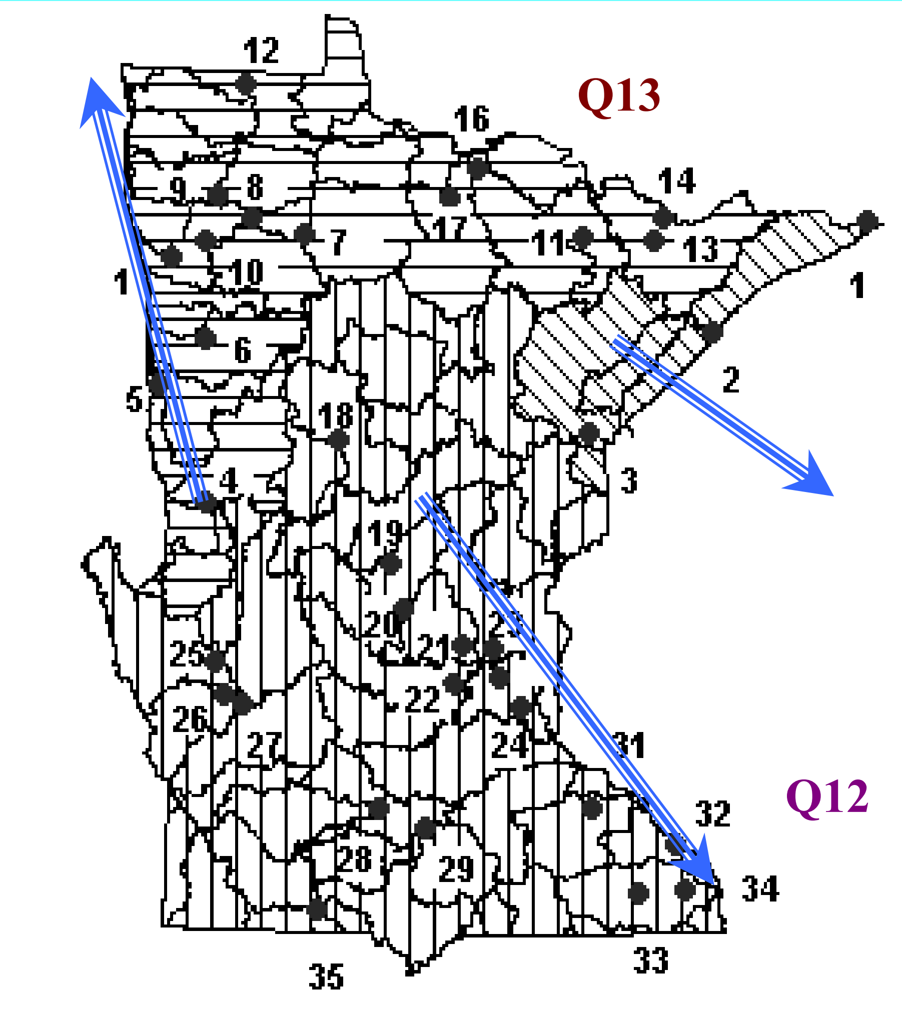
BALANCING WATER FOR HUMANS AND NATURE

A Need for New Paradigm

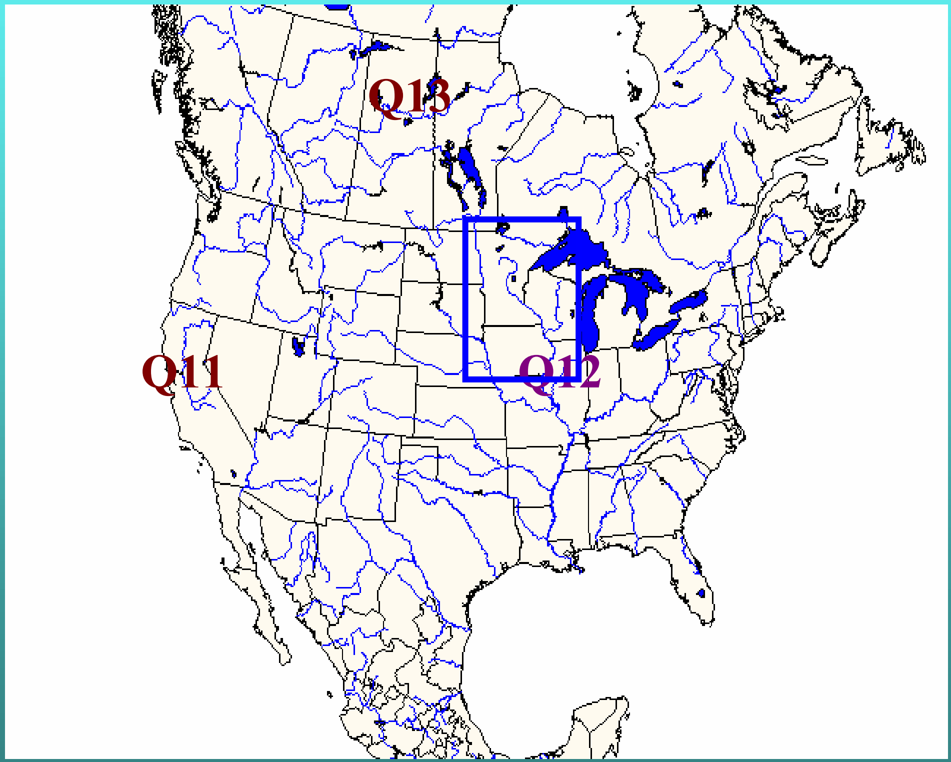
- viewing precipitation as gross freshwater resources to sustain human and natural systems
- renewable freshwater resources via recharge/ discharge constants at a multiple scale
- fresh ground-water resources must be quantified using multiscale recharge/discharge mapping

The specific hydrologic characteristics used in analysis are:

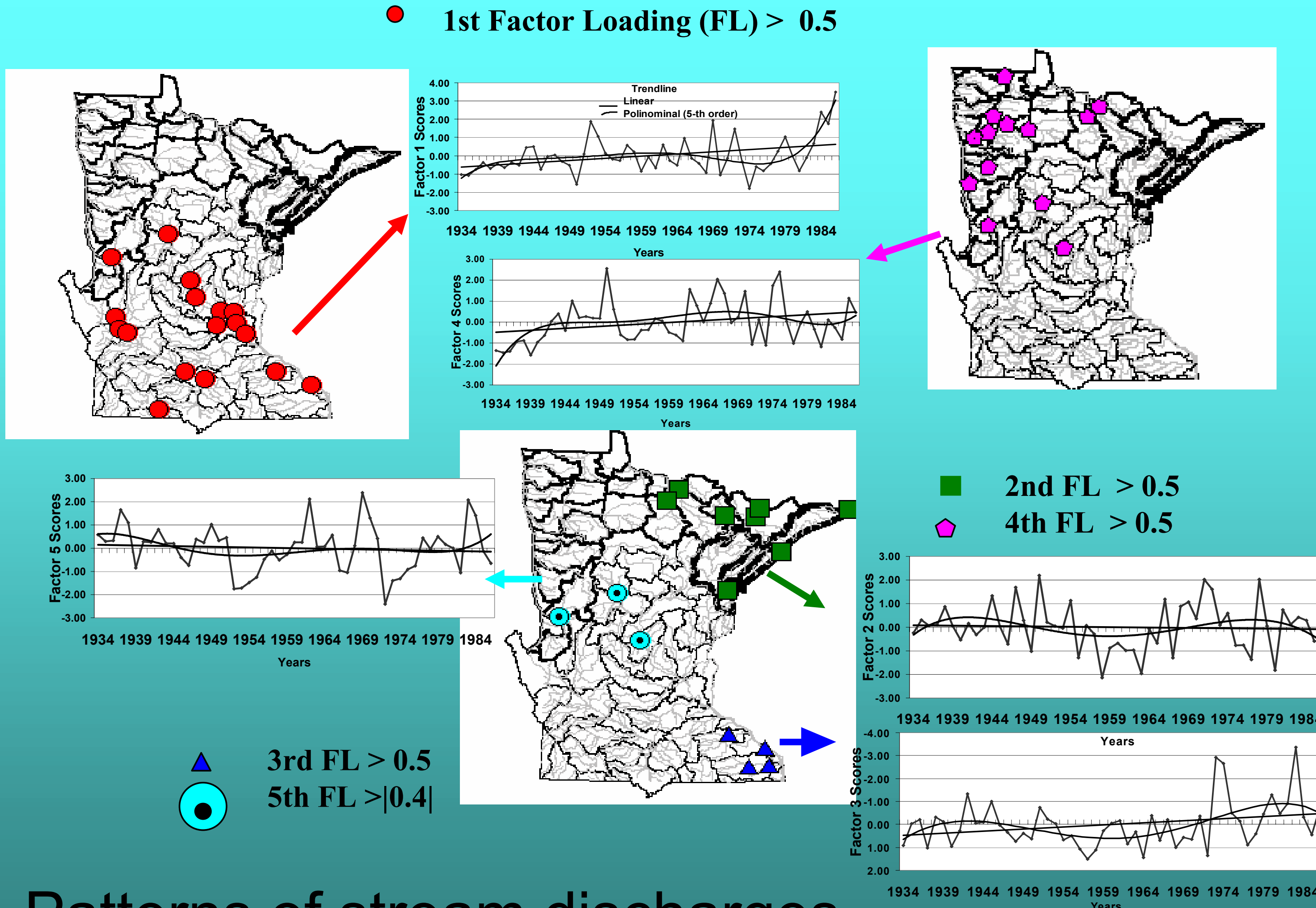
- **average annual stream runoff rate (modulus) [l/s/sq. km or mm/year]**
- **average rate (modulus) of minimal monthly stream runoff [l/s/sq. km or mm/year]**



Mississippi River Basin, Hudson Bay Drainages, Lake Superior Drainages

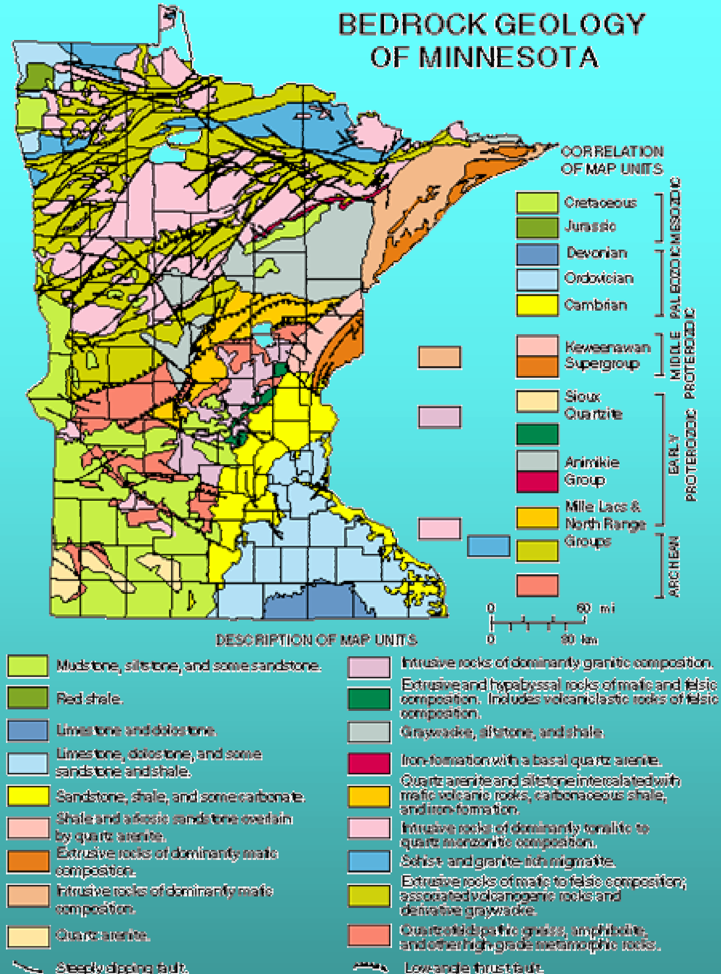


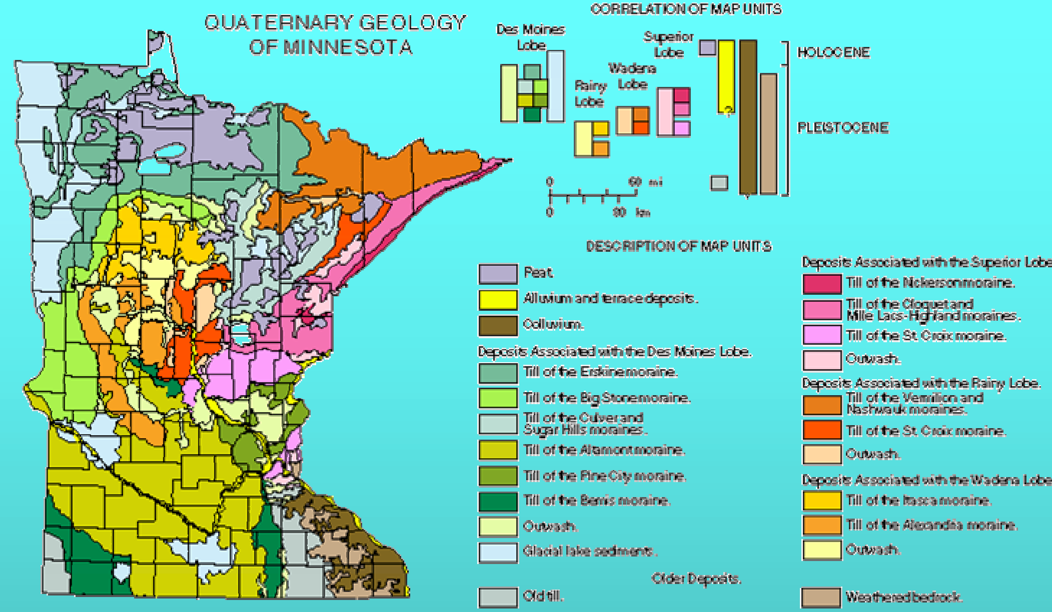
Stream discharges in Minnesota. Location of 35 gauging stations and the major World watersheds

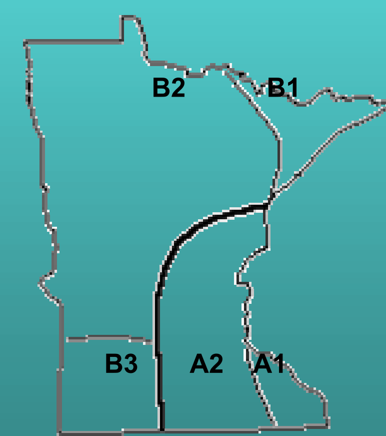


Patterns of stream discharges

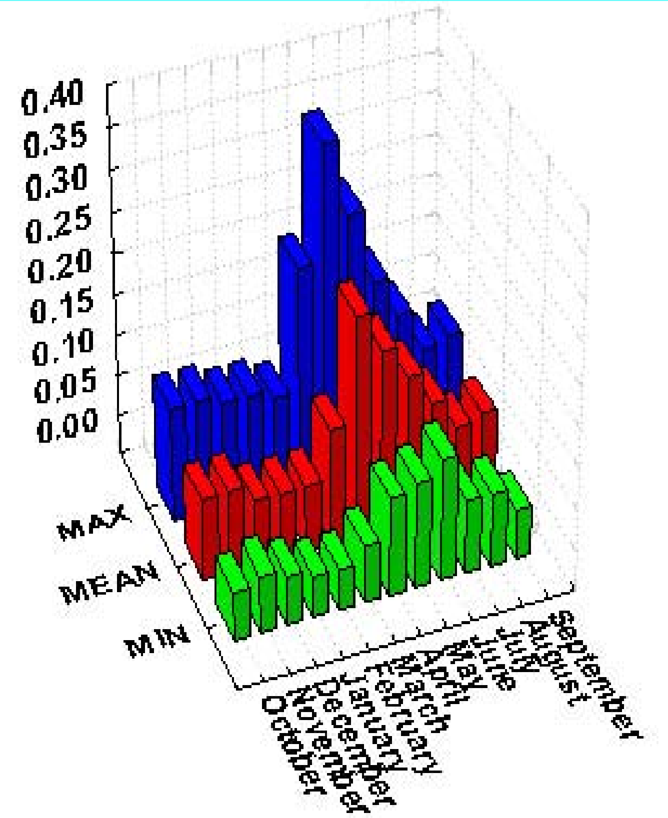
and location of gauging stations with Factor Loading and graphs of five Factors Scores

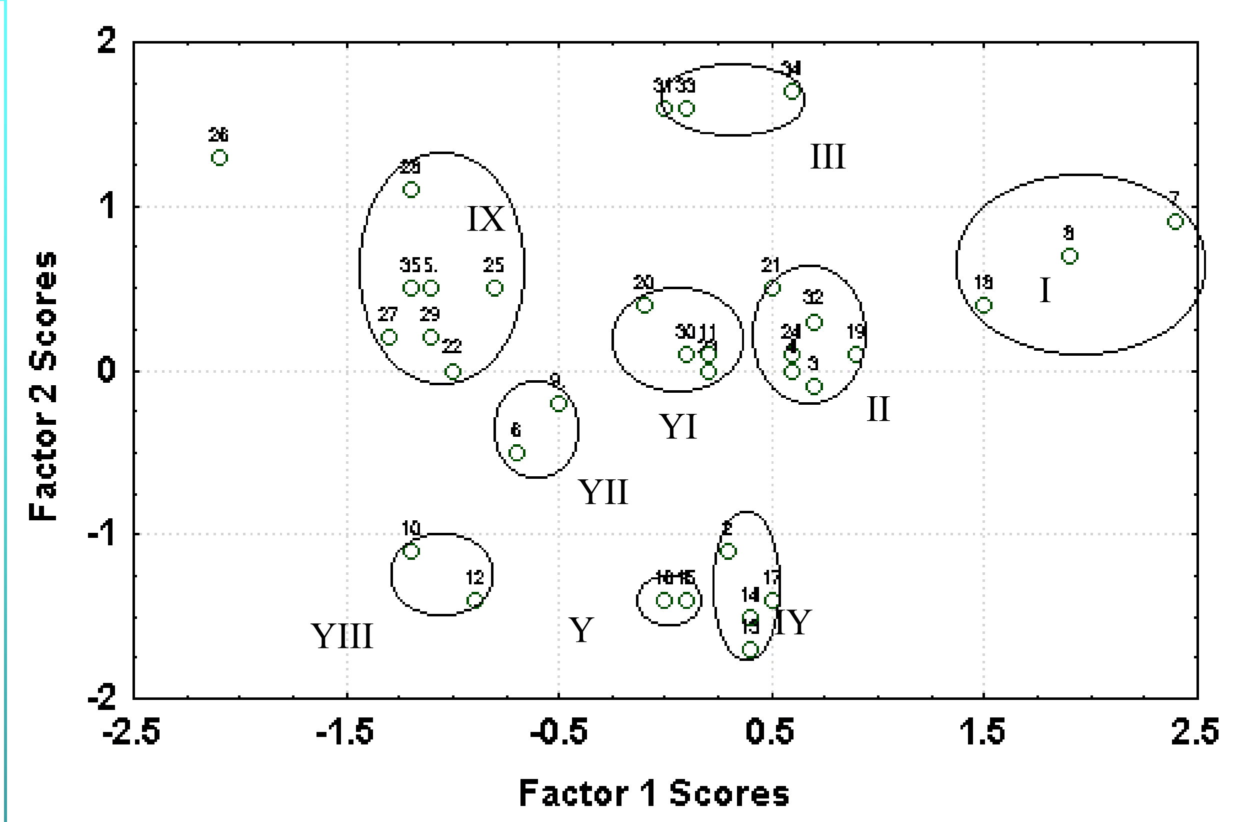






Geologic maps and hierarchical hydrogeological subdivision

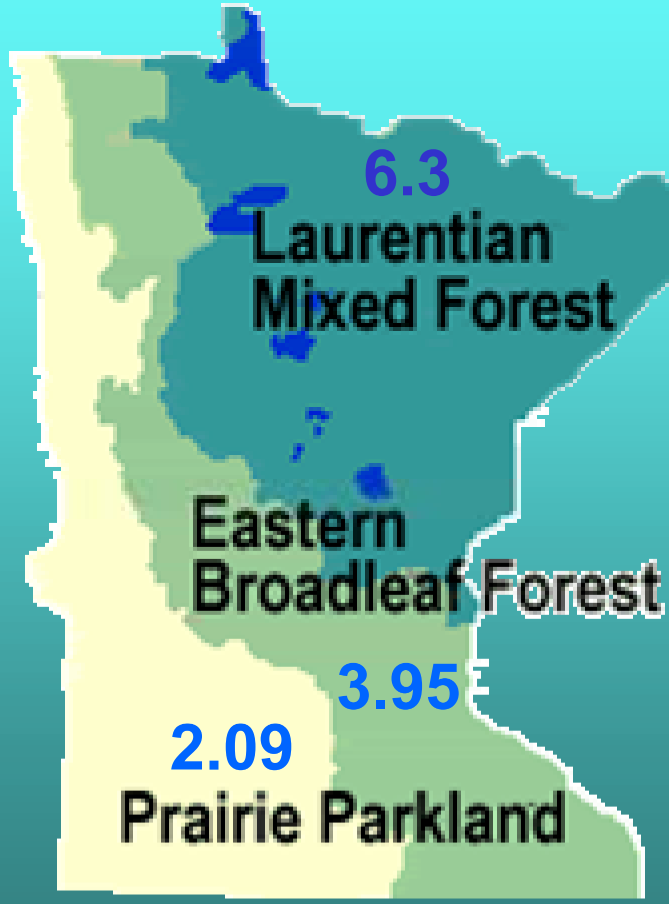


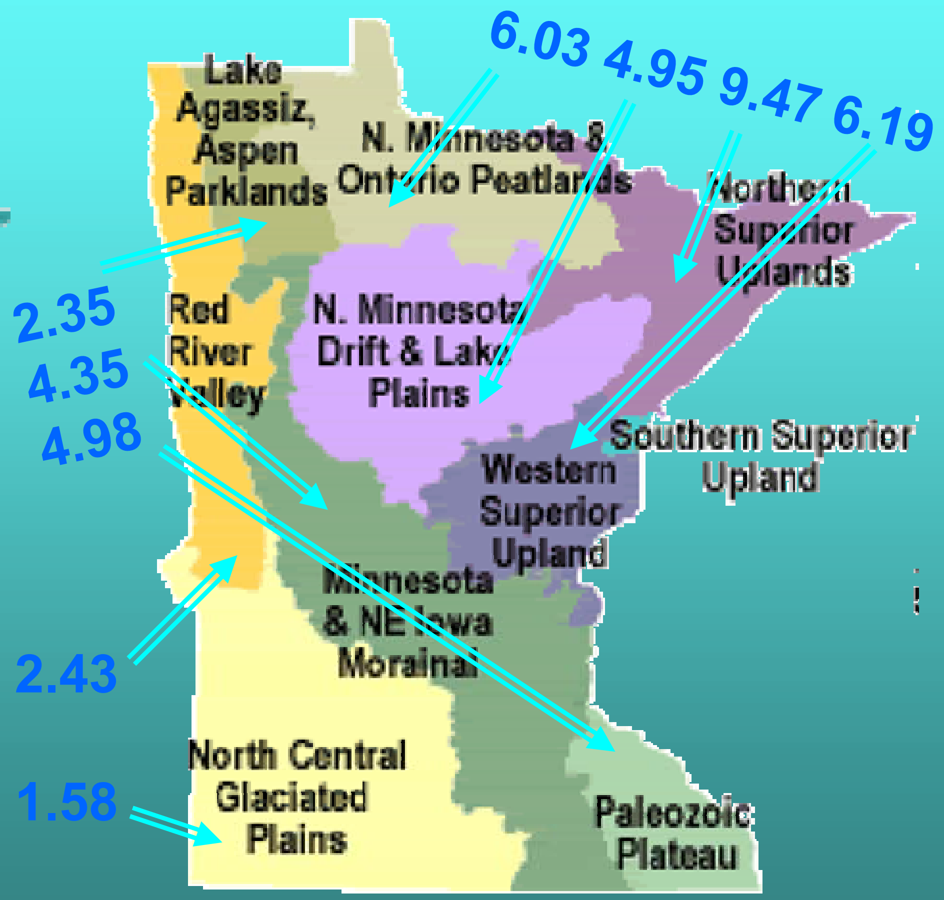


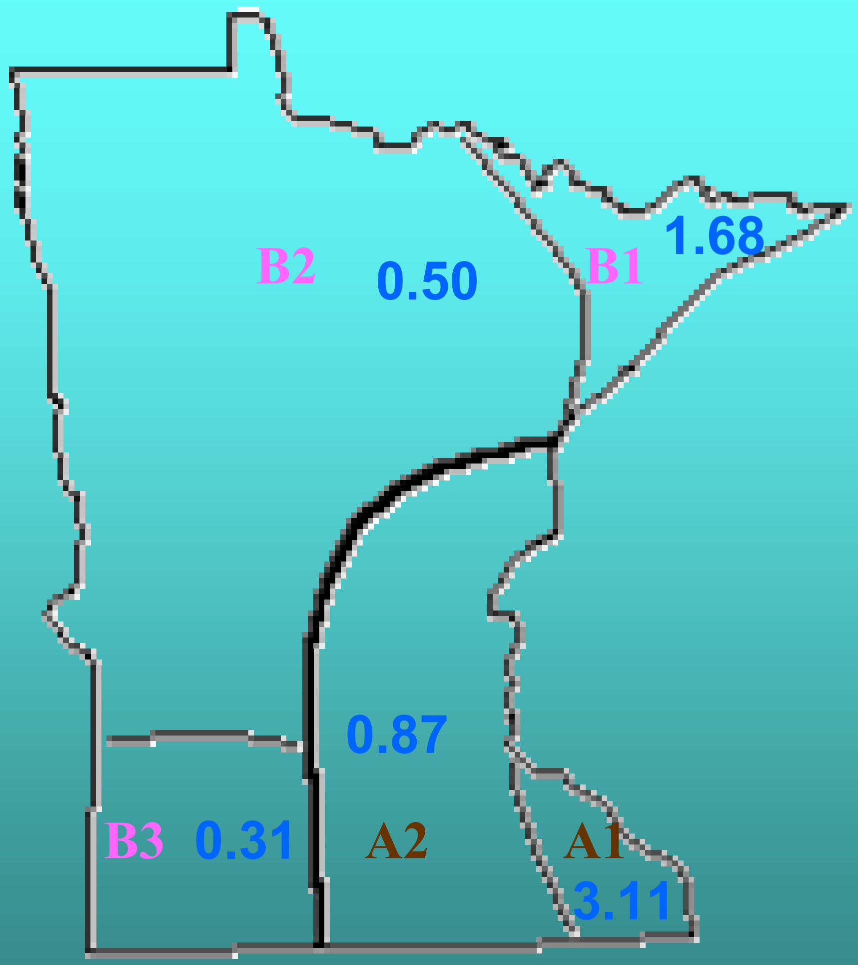
Average proportions of monthly discharge for 35 Minnesota streams for period 1935-86 and the watersheds in factor scores plane.

Annual stream runoff for Ecological Provinces & Sections

Values are of Stream Runoff in [cfs/sq mi]







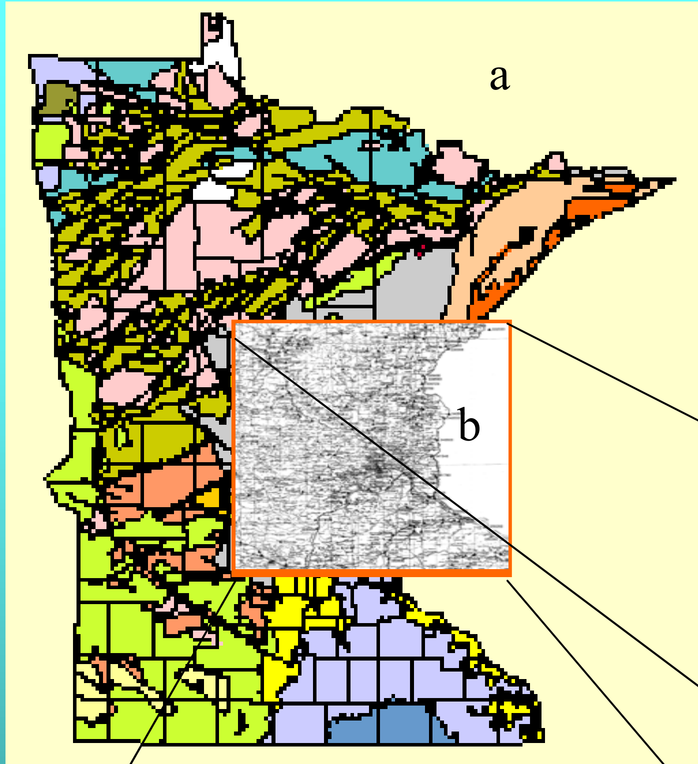
Minimal monthly stream runoff in Minnesota

A= 2.09

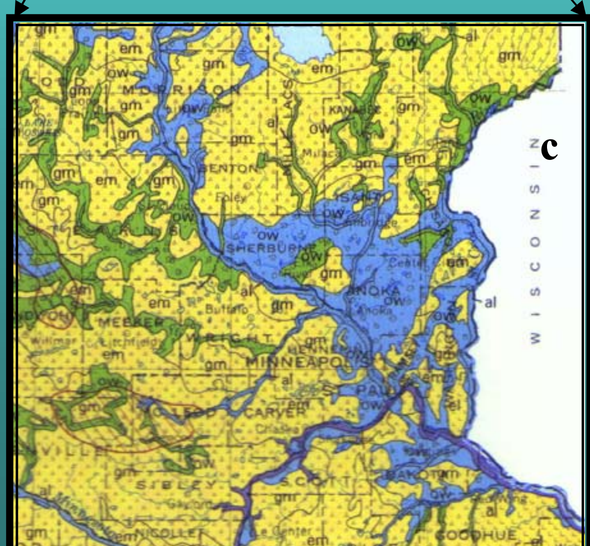
B= 1.14

Values are February Stream Runoff in [cfs/sq mi]

Minnesota and East Central Minnesota (ECM)



a- geologic map for state with county boundaries and b- the territory of ECM with a red rectangle is a map with gauging stations and records of low stream runoff (after Lindskov, 1977), c- Quaternary and d- bedrock maps (after Kanivetsky, 1978, 1979)



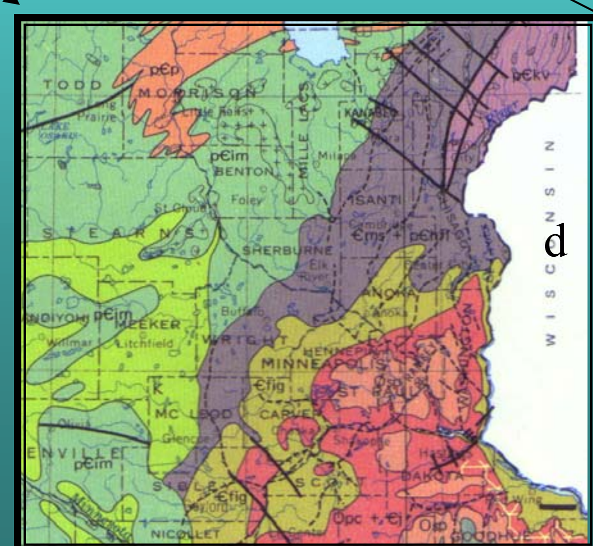


Table of average rates of

minimal ground-water discharge/recharge for ECM

Symbol and Hydrogeologic Region (Number of watersheds used)	Recharge Mean (Ranges: Low & Upper Quartile) [l/s/sq. km]	Symbol and Hydrogeologic Subregion (Number of watersheds used)	Recharge Mean (Ranges: Low & Upper Quartile) [l/s/sq. km]	Symbol and Hydrogeologic District (Number of watersheds used)	Recharge Mean (Ranges: Low & Upper Quartile) [l/s/sq. km]	Symbol and Hydrogeolic Subdistrict (Number of watersheds used)	Recharge Mean (Ranges: Low & Upper Quartile) [l/s/sq. km]
PB- Precambrian Basement (49)	0.59 (0.24-0.69)	**B/Q-** Two ground-water flow field layers: Quaternary sediments and Precambrian Basement (43)	0.63 (0.28-0.78)			**B/Q1**- overlain by sand and gravel (18)	0.90 (0.45-1.22)
						B/Q2- overlain by clayey till(15)	0.31 (0.11-0.51)
						B/Q3- overlain by sandy till (11)	0.59 (0.33-0.82)
		B/K/Q- Three ground-water flow field layers: Quaternary sediments, Cretaceous confining unit and Precambrian Basement (5)	0.26 (0.1-0.5)			**B/K/Q2-** overlain by clayey till (4)	0.20 (0.06-0.34)
PAB- Paleozoic Artesian Basin (88)	1.67 (0.52-2.37)	**A**- One ground-water flow field layer: Paleozoic artesian aquifers (exposed or shallow bedrock) (27)	3.11 (2.06-4.23)	**A2**- Franconia- Ironton- Galesville aquiter (mixed shale, sandstone, some shaly carbonates)		**A2/Q-** Overlain by sediments in valley of Mississippi River (7)	2.90 (0.78-4.72)
				A3&4- Prairie du Chien Jordan aquifer (sandstone, limestone) (16)	3.56 (2.51-4.48)		
				A5- St. Peter aquifer (sandstone) (4)	1.71 (1.41-2.01)		
		A/Q- Two ground-water flow field layers: Quaternary sediments and Paleozoic artesian aquifers (58)	1.06 (0.41-1.24)	**A1/Q-** Quaternary sediments and Mt. Simon-Hinckley-Fond du Lac aquifer (sandstone) (23)	1.01 (0.51-1.10)	**A1/Q1-** overlain by sand and gravel (10)	1.43 (0.51-2.12)
						A1/Q2- overlain by clayey till (7)	0.70 (0.51-0.96)
						A1/Q3- overlain by sandy till (8)	0.75 (0.54-0.96)
				A2/Q- Quaternary sediments and Franconia-Ironton- Galesville aquiter (mixed shale, sandstone, some shaly carbonates) (3*)	0.58 (-)*	**A2/Q1**- overlain by sand and gravel (1)*	1.24 (-)*
						A2/Q2- overlain by clayey till (2)* */- not sufficient set for statistical analysis	0.26 (-)*
				A3&4/Q- Quaternary sediments and Prairie du Chien Jordan aquifer (sandstone, limestone) (12)	0.98 (0.34-1.18)	**A3&4/Q1**- overlain by sand and gravel (4)	1.56 (0.36-2.76)
						A3&4/Q2- overlain by clayey till (8)	0.70 (0.29-1.07)
				A5/Q- Quaternary sediments and St. Peter aquifer (sandstone) (20)	1.23 (0.54-1.81)	**A5/Q1**- overlain by sand and gravel (5)	1.74 (1.44-2.16)
						A5/Q2- overlain by clayey till (15)	1.06 (0.38-1.44)

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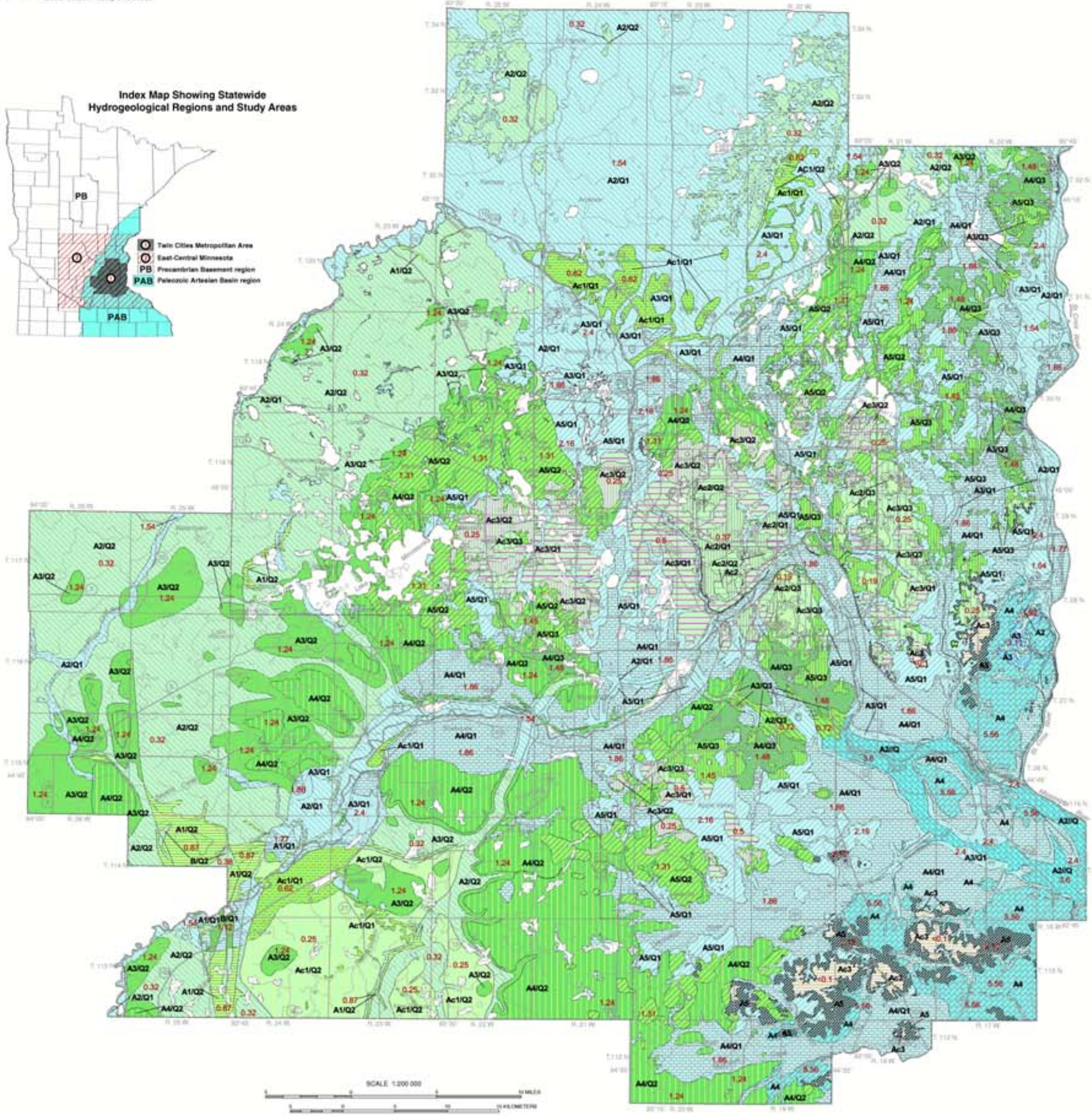


Minimal Annual Ground-Water Recharge Based on February Monthly Discharge Mean Measurements Period 1935-1981

Symbol and Hydrogeologic Region and Subregion		Symbol and Hydrogeologic District (Number of watersheds used)	District Recharge Mean (Only units with color appear on map) (*Low & Upper Quartile) [inches per year]	Symbol and Hydrogeologic Subdistrict (Number of watersheds used)	Subdistrict Recharge Mean (*Lower & Upper Quartile) [inches per year]
PB- Precambrian Basement	B/Q- Two ground-water flow field layers	B/Q- Two ground-water flow field layers: Quaternary sediments and Precambrian Basement (intrusive and extrusive rocks)		B/Q1- overlain by sand and gravel (18)	1.12 (0.56-1.51)
				B/Q2- overlain by clayey till (15)	0.38 (0.14-0.63)
PAB- Paleozoic Artesian Basin	A- One ground-water flow field layer: Paleozoic artesian aquifers (exposed or shallow bedrock)	A2- Franconia- Ironton- Galesville aquifer (mixed shale, sandstone, some shaly carbonates)	1.92	A2/Q- overlain by sediments in valley of Mississippi River (7)	3.60 (0.97-5.85)
		A3- Jordan aquifer (sandstone)	3.11		
		A4- Prairie du Chien aquifer (limestone)	5.56		
		Ac2- Decorah confining unit (most tight and homogeneous shale)	<0.1		
		Ac3- Platteville Glenwood confining unit (dolomitic limestone and shale)	<0.1		
		A5- St. Peter aquifer (sandstone) (4)	2.12 (1.75-2.42)		
	A/Q- Two ground-water flow field layers: Quaternary sediments and Paleozoic artesian aquifers	A1/Q- Quaternary sediments and Mt. Simon- Hinckley- Fond du Lac aquifer (sandstone) (23)	1.25 (0.63-1.36)	A1/Q1- overlain by sand and gravel (10)	1.77 (0.63-2.64)
				A1/Q2- overlain by clayey till (7)	0.87 (0.63-1.19)
		Ac1/Q- St. Lawrence confining unit (shale with some limestone)		Ac1/Q1- overlain by sand and gravel	0.62
				Ac1/Q2- overlain by clayey till	0.25
		A2/Q- Quaternary sediments and Franconia- Ironton- Galesville aquifer (mixed shale, sandstone, some shaly carbonates) (3)	0.72†	A2/Q1- overlain by sand and gravel (1)	1.54†
				A2/Q2- overlain by clayey till (2)	0.32†
				A2/Q3- overlain by sandy till	0.72
		A3/Q- Quaternary sediments and Jordan aquifer (sandstone)		A3/Q1- overlain by sand and gravel	2.4
				A3/Q2- overlain by clayey till	1.24
				A3/Q3- overlain by sandy till	1.48
		A4/Q- Quaternary sediments and Prairie du Chien aquifer (limestone)		A4/Q1- overlain by sand and gravel	1.86
				A4/Q2- overlain by clayey till	1.24
				A4/Q3- overlain by sandy till	1.48
		Ac2/Q- Decorah confining unit (most tight and homogeneous shale)		Ac2/Q1- overlain by sand and gravel	0.37
				Ac2/Q2- overlain by clayey till	0.12
				Ac2/Q3- overlain by sandy till	0.19
		Ac3/Q- Platteville Glenwood confining unit (dolomitic limestone)		Ac3/Q1- overlain by sand and gravel	0.5
				Ac3/Q2- overlain by clayey till	0.25
				Ac3/Q3- Overlain by sandy till	0.25
		A5/Q- Quaternary sediments and St. Peter aquifer (sandstone) (20)	1.53 (0.67-2.24)	A5/Q1- overlain by sand and gravel (5)	2.16 (1.79-2.68)
				A5/Q2- overlain by clayey till (15)	1.31 (0.47-1.79)
				A5/Q3- overlain by sandy till	1.45

* Ranges are shown where data were available

† Insufficient set for statistical analysis

Minimal Annual Ground-Water Recharge Ranges (inches per year)

- > 2.5
- 1.5 - 2.5
- 0.5 - 1.5
- 0.1 - 0.5
- < 0.1

Minimal Annual Ground-Water Recharge in the Twin Cities Seven-County Metropolitan Area

Roman Kanivetsky and Boris Shmagin

2001

Minimal ground-water recharge in Twin Cities Metropolitan area

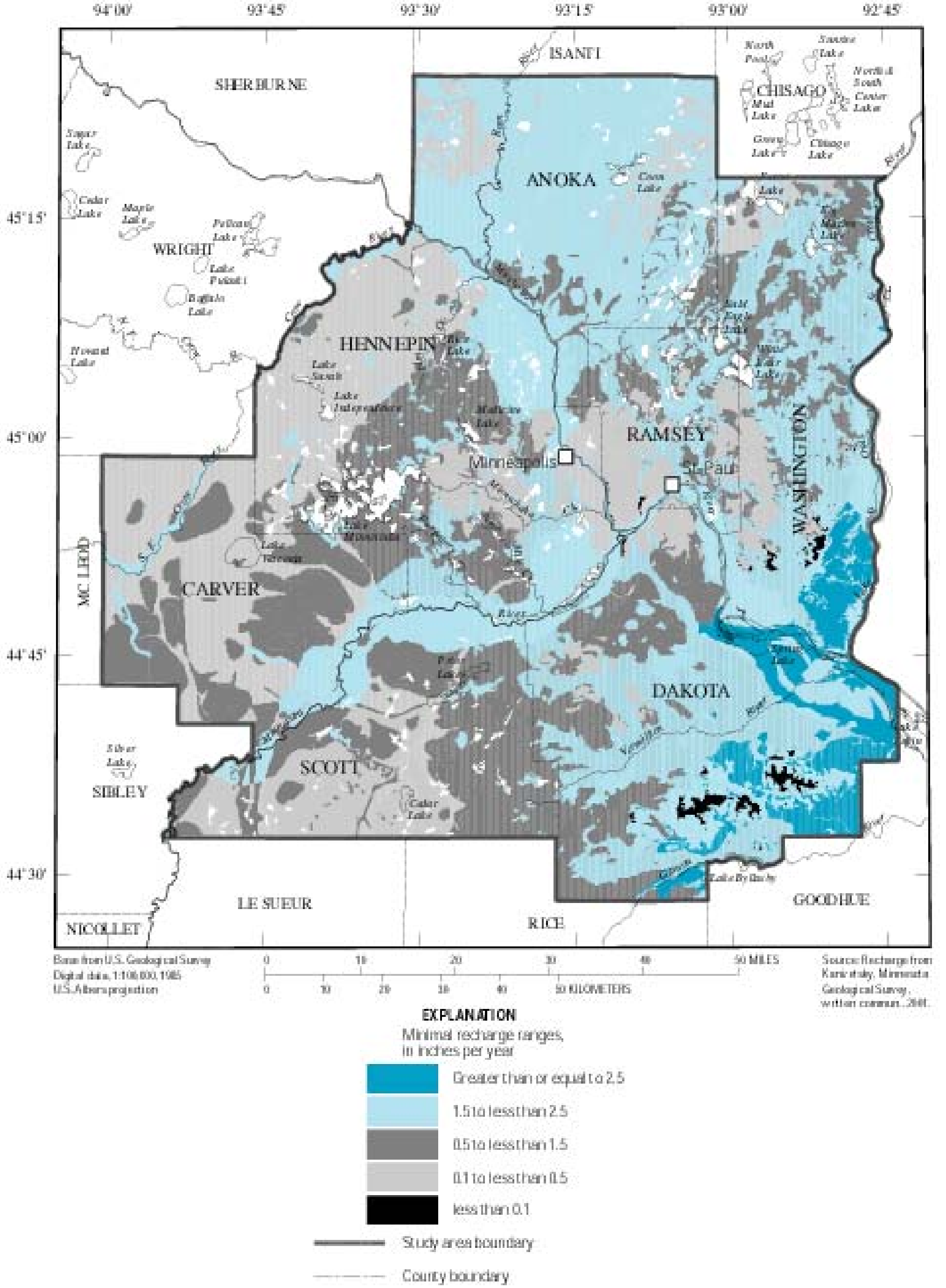
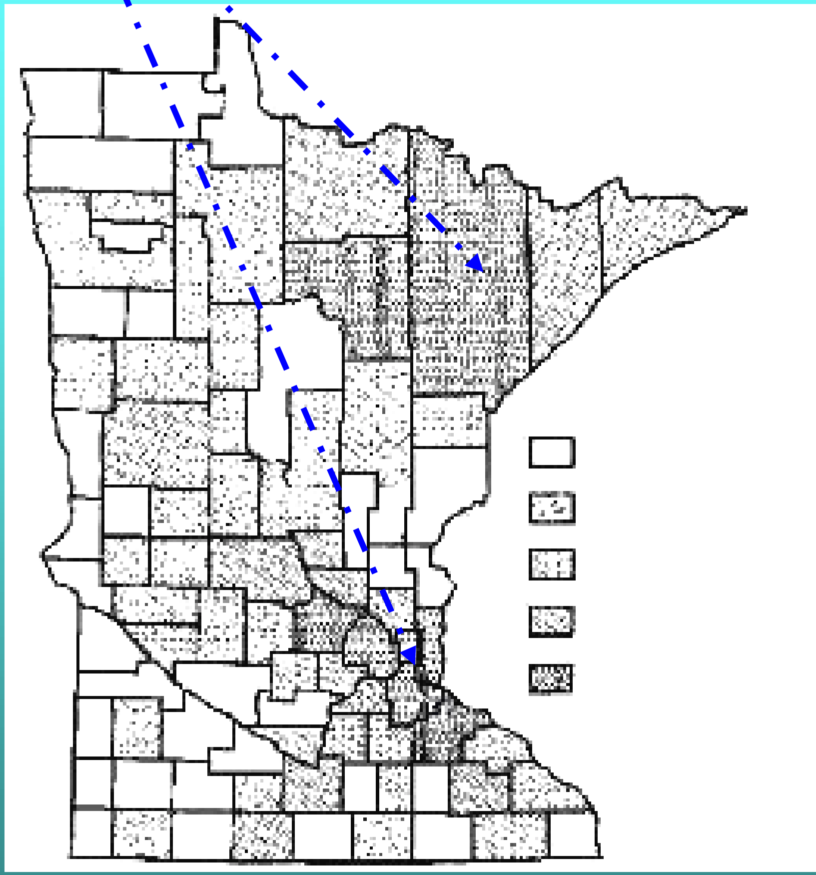
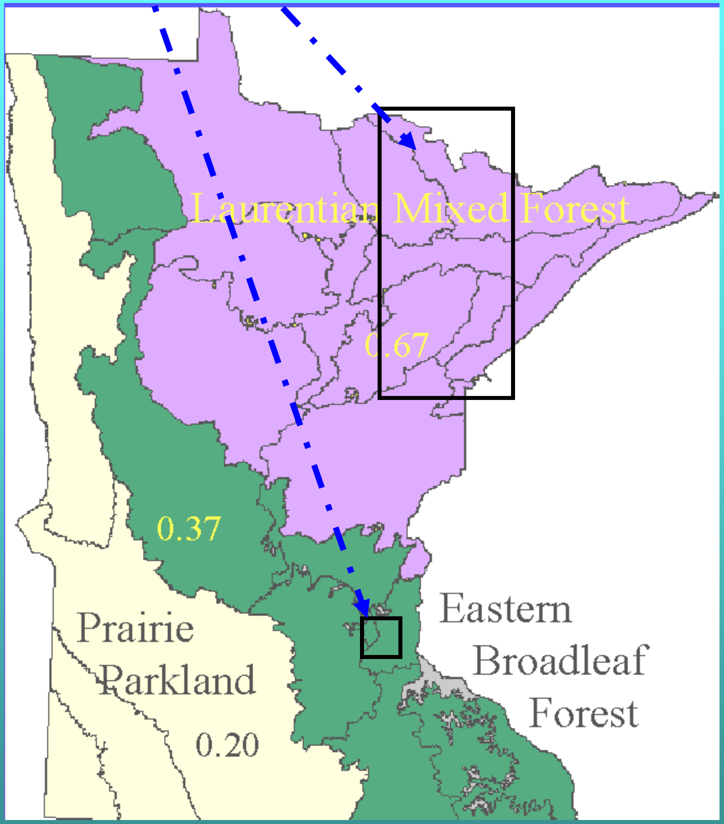


Figure 6. Minimal ground-water recharge based on statistical analyses of watershed characteristics in the Twin Cities metropolitan study area, Minnesota.

County	Land Area [sq. mi]	Water Use: Surface*	Ground*	Total*
St. Louis	6321	0.06	0.001	0.061
Ramsey	158.2	0.93	0.46	1.39

County	Water: Use* /	Resources**	= %
St. Louis	0.061	0.67	8.1
Ramsey	1.39	0.37	366.0





Sustainable water resources and water use in Minnesota.
a. Water use in cfs/sq. mi. (Water Year, 1995 &1996, DNR data)
b. Water resources in cfs/sq. mi. (after Shmagin and Kanivetsky, 2002) versus water use.

Quantitative information system for ground-water sustainability planning

- GIS recharge/discharge maps at a multiple scales
- GIS water use coding to the areas units on recharge/discharge maps
- Expert information and decision support system for sustainable planning.