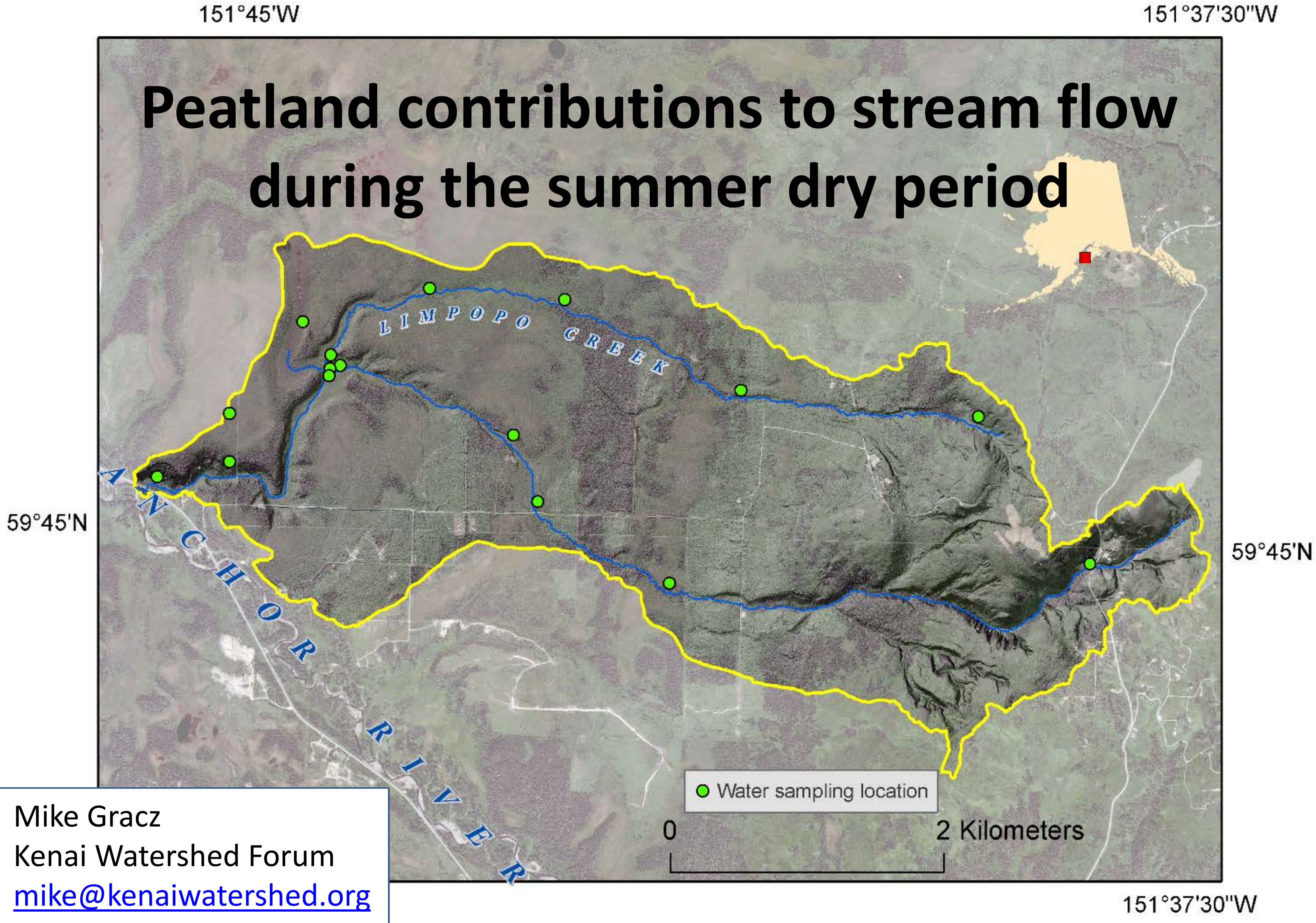
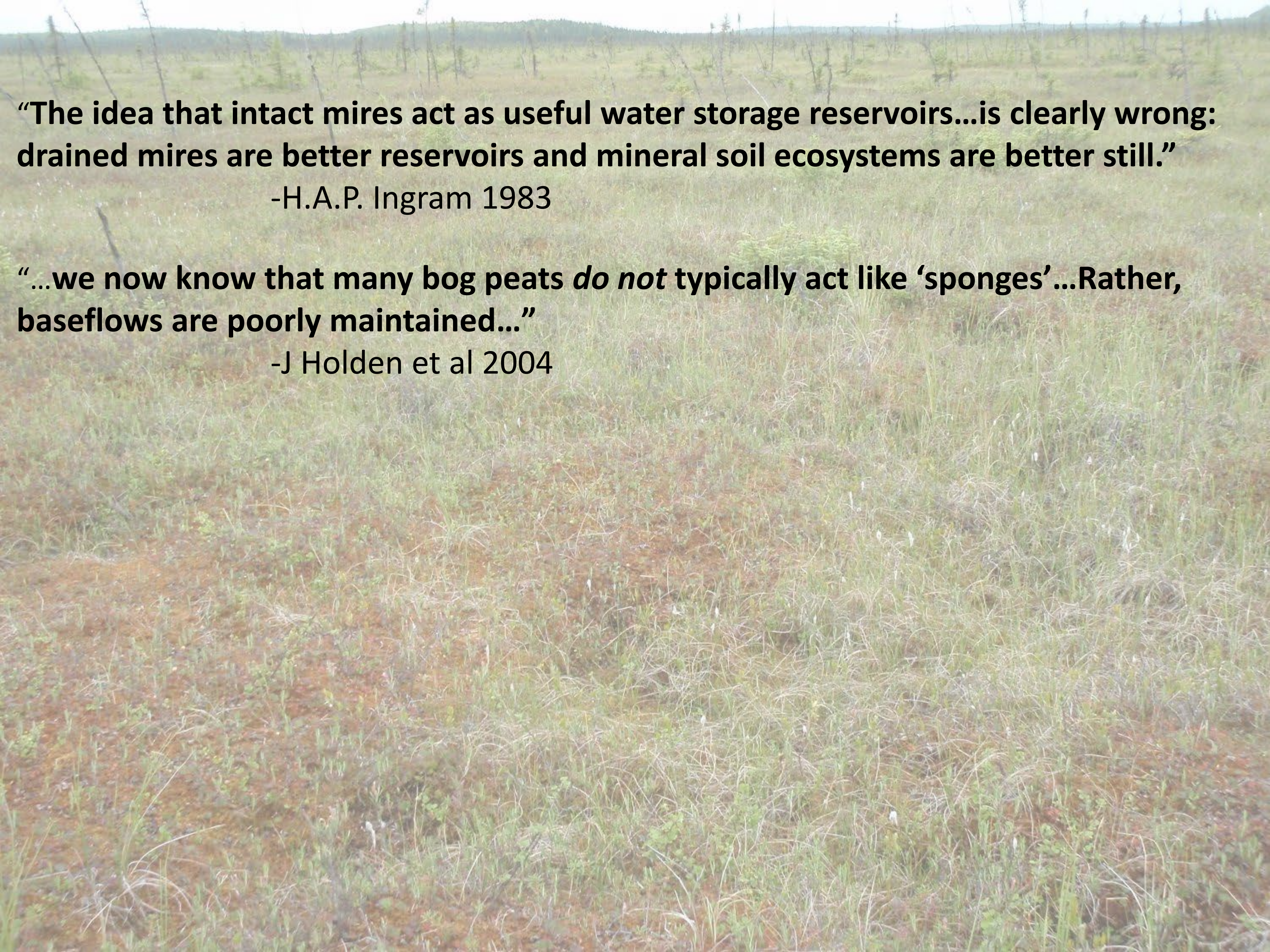
Peatland contributions to stream flow during the summer dry period



Mike Gracz
Kenai Watershed Forum
mike@kenaiwatershed.org
907-235-2218

Gracz, Moffett, Siegel, Glaser, 2015. Journal of Hydrology (530)667-676

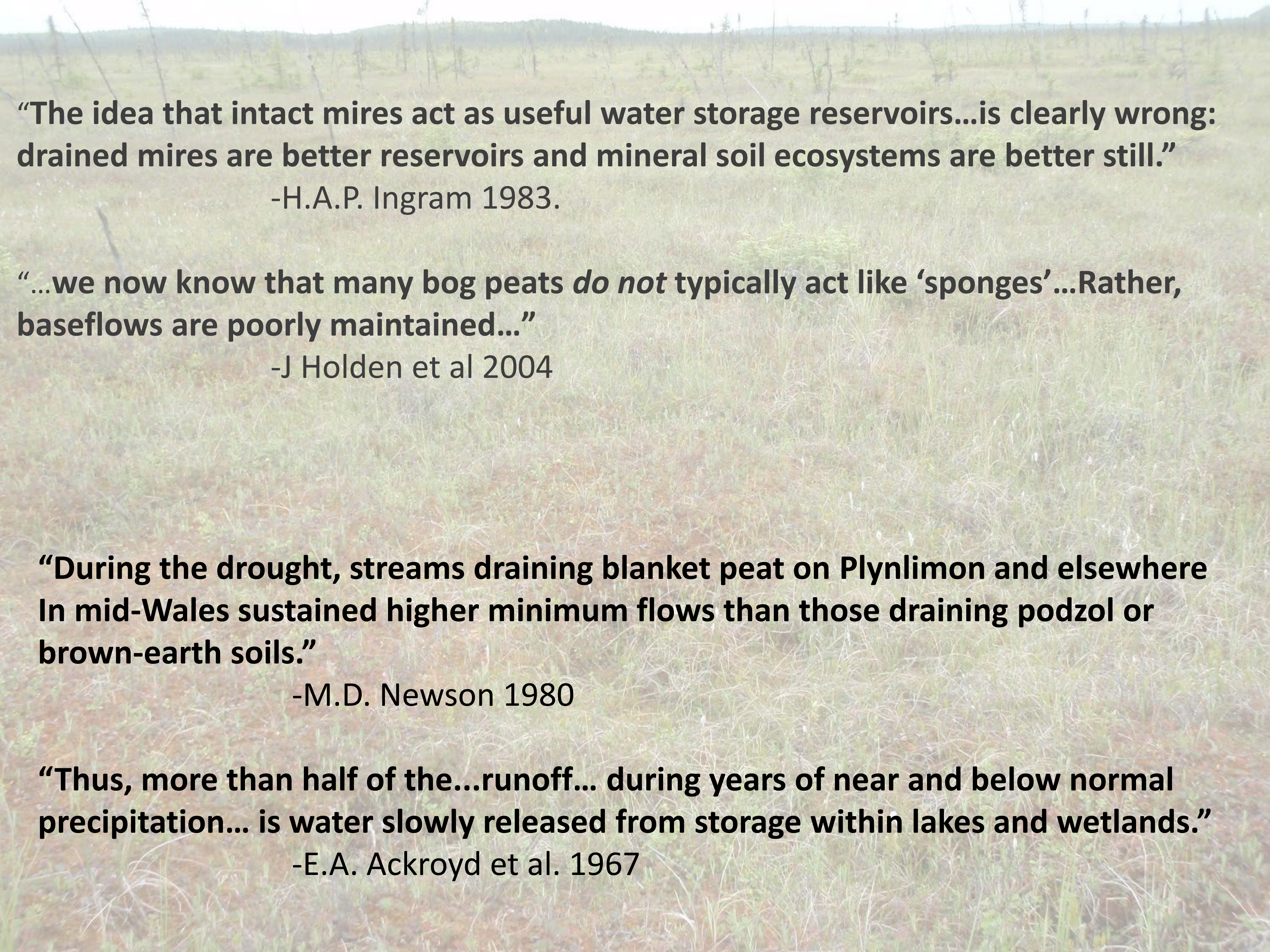


“**The idea that intact mires act as useful water storage reservoirs…is clearly wrong: drained mires are better reservoirs and mineral soil ecosystems are better still.”**

-H.A.P. Ingram 1983

“…**we now know that many bog peats *do not* typically act like ‘sponges’…Rather, baseflows are poorly maintained…”**

-J Holden et al 2004



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“…**we now know that many bog peats *do not* typically act like ‘sponges’…Rather, baseflows are poorly maintained…”**

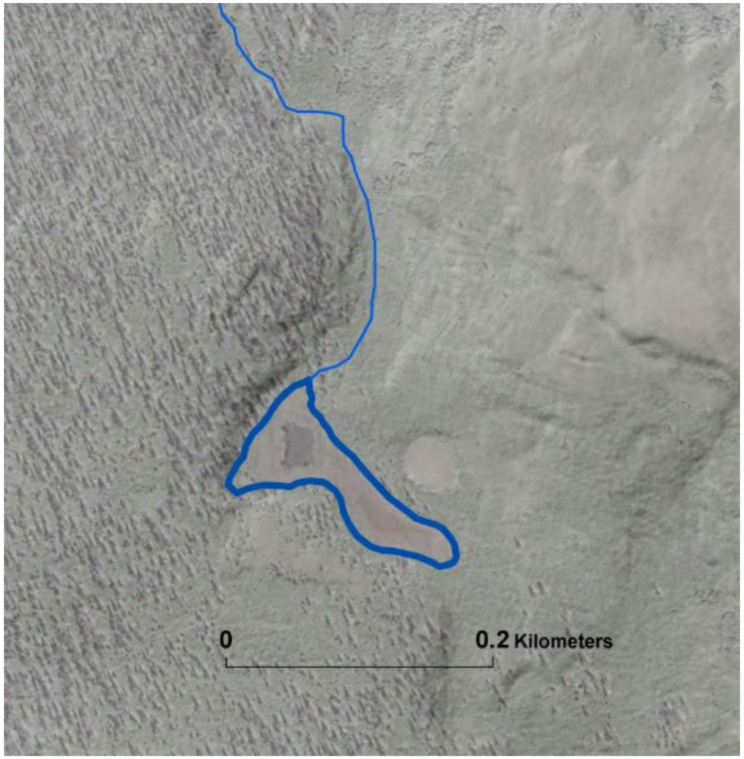
-J Holden et al 2004

“During the drought, streams draining blanket peat on Plynlimon and elsewhere In mid-Wales sustained higher minimum flows than those draining podzol or brown-earth soils.”

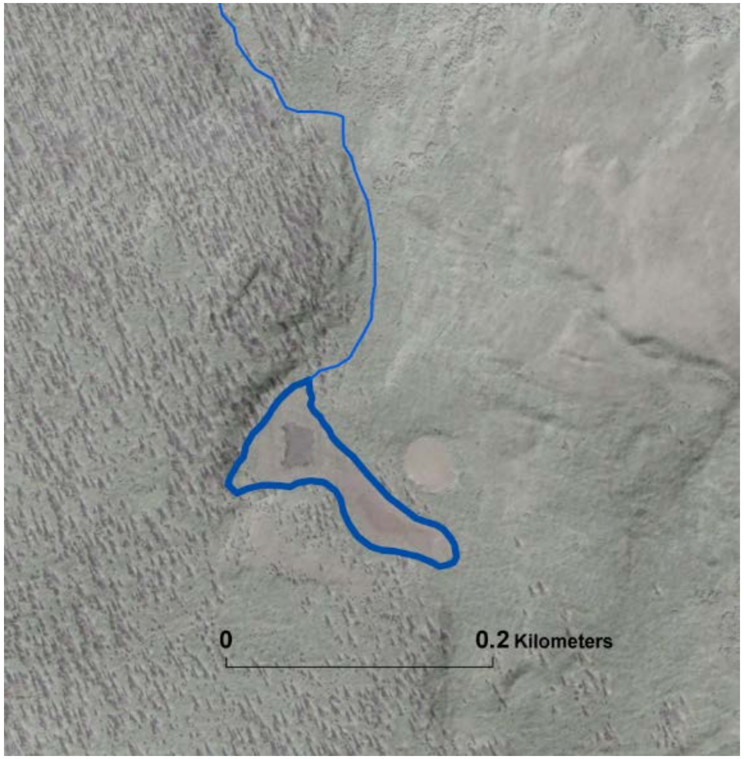
-M.D. Newson 1980

“Thus, more than half of the...runoff… during years of near and below normal precipitation… is water slowly released from storage within lakes and wetlands.”

-E.A. Ackroyd et al. 1967



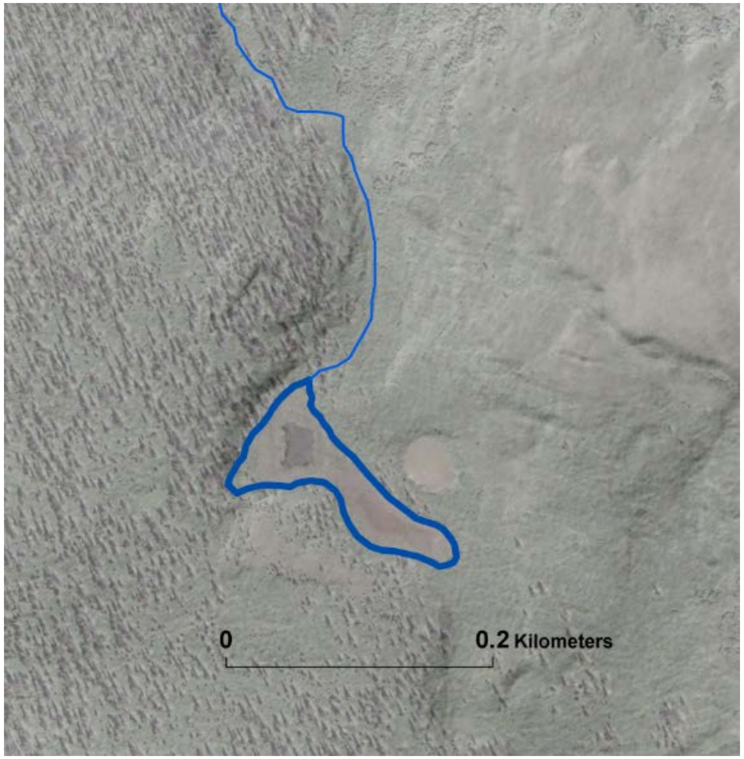
“Stream flow is most easily measured on small watersheds containing lake-filled peatland”



"Stream flow is most easily measured on small watersheds containing lake-filled peatland"

"…rainfall is quickly returned to the atmosphere by evapotranspiration at the expense of stream flow…"

-Boelter & Verry 1977



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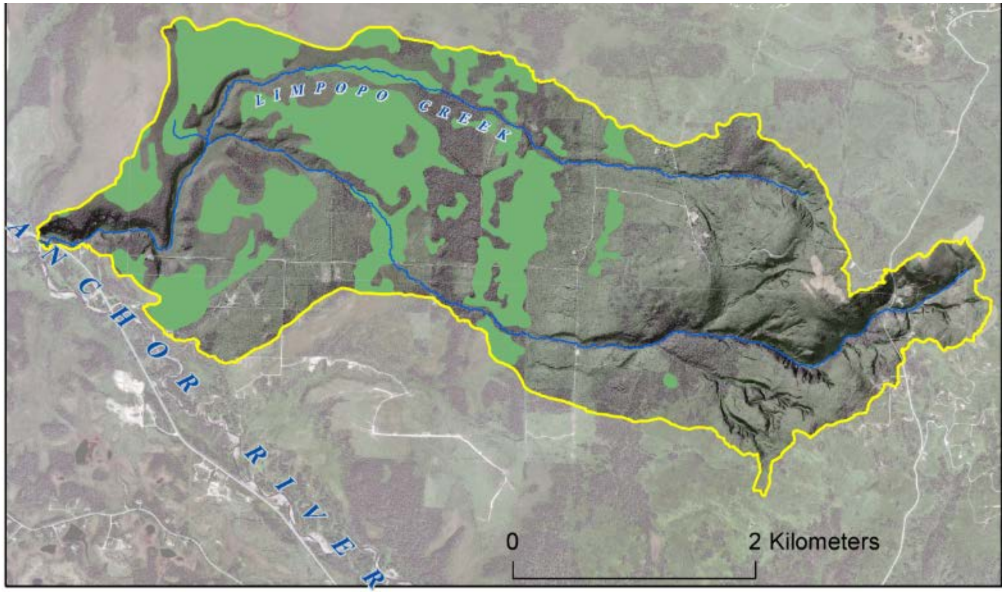
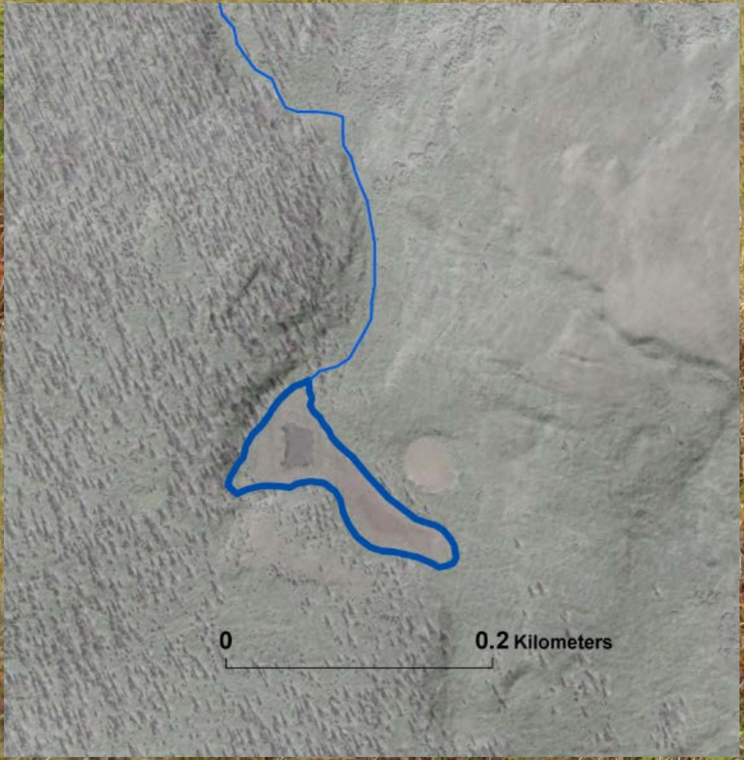
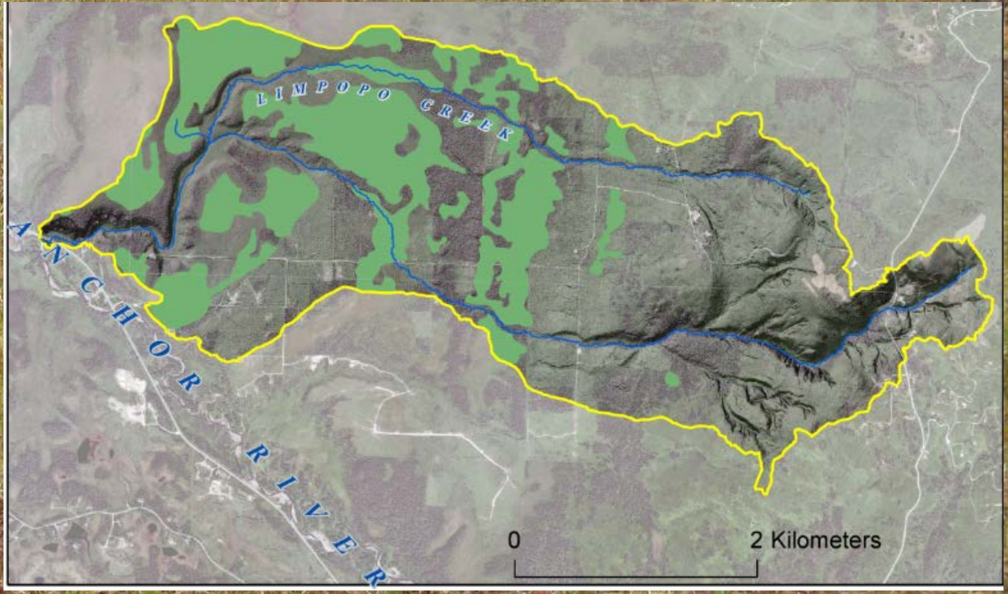
Diffuse flow from large lakebed peatlands is more difficult to measure

A more common and extensive type of peatland



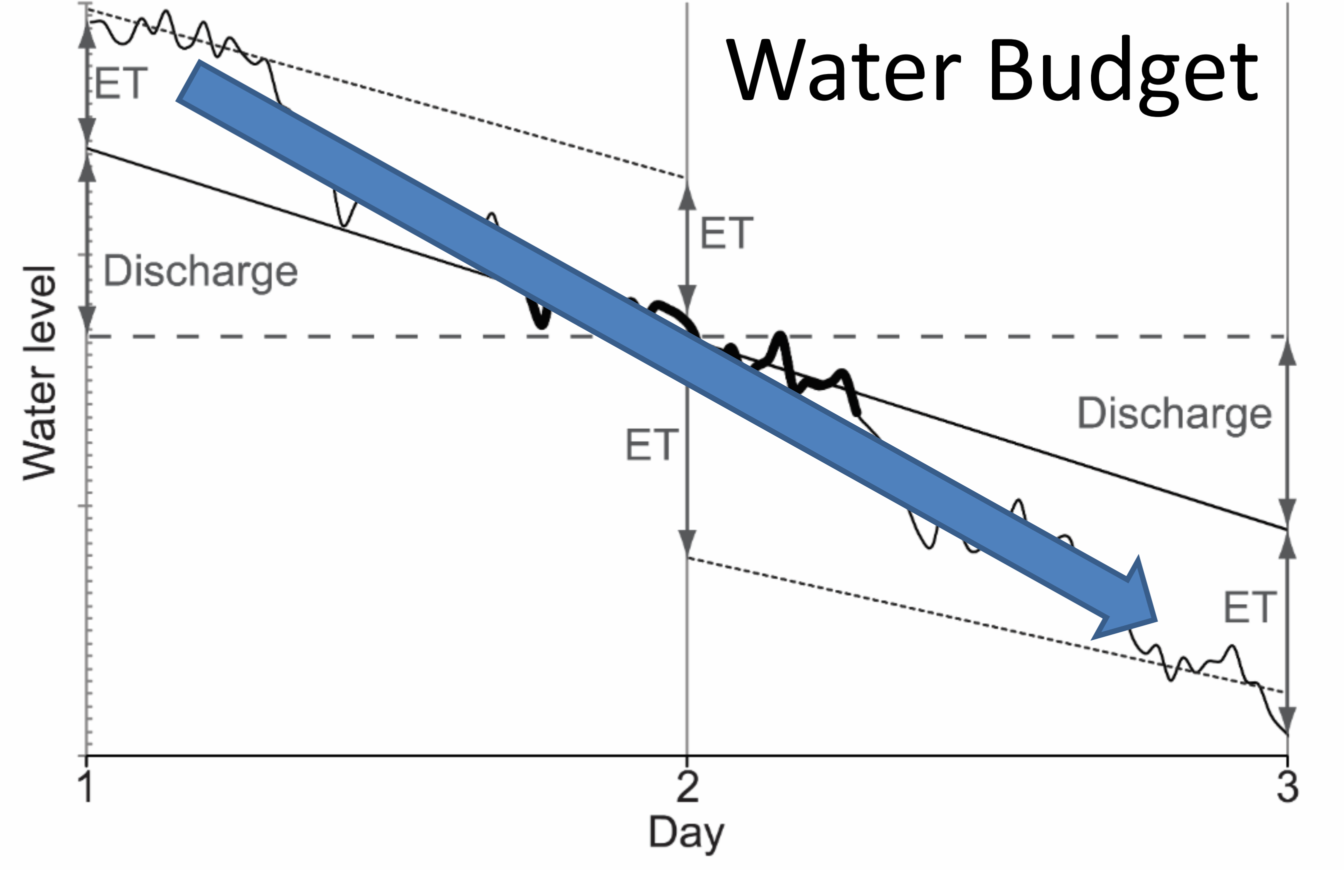
Hydrogeologic setting is important



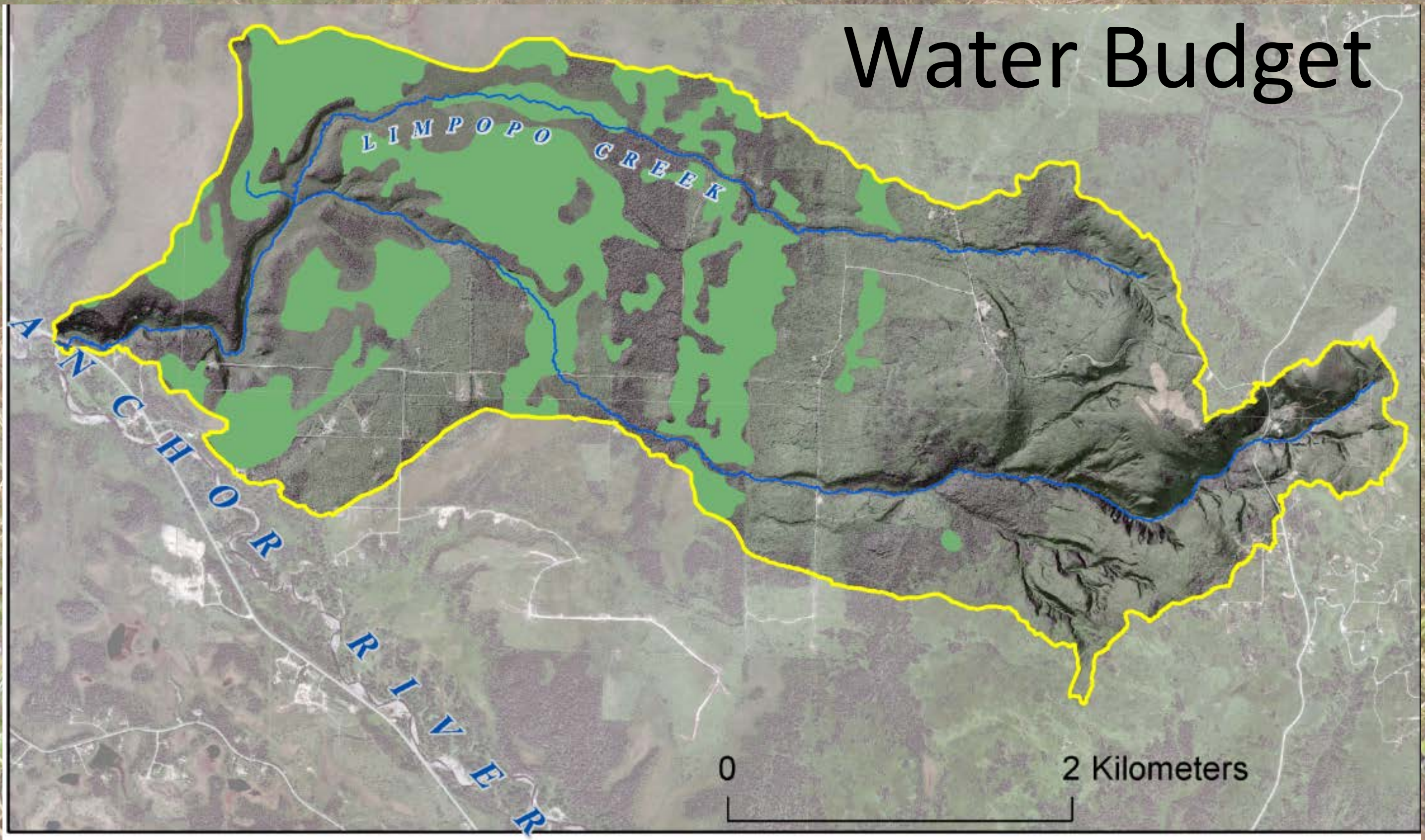


How to measure?

Water Budget

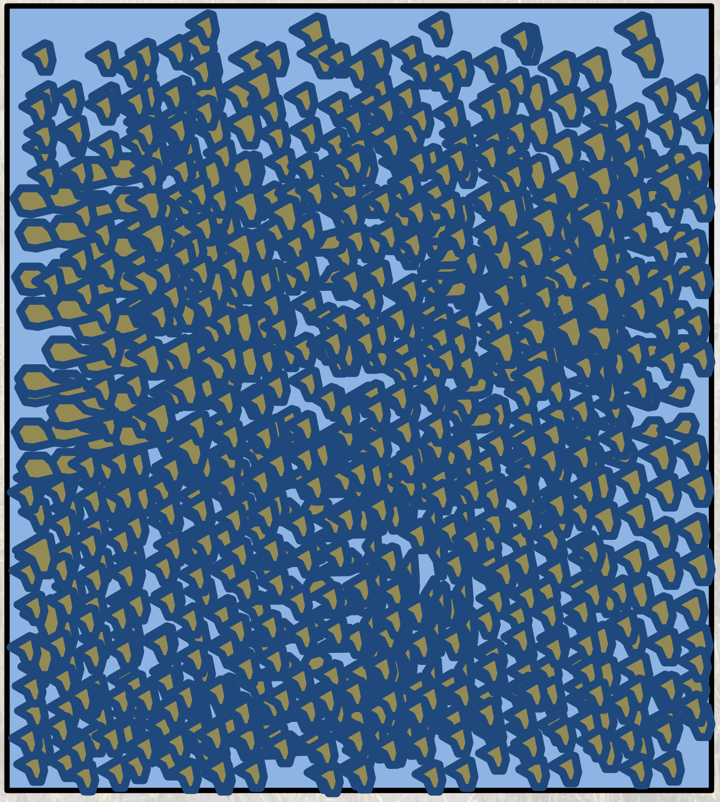


How to measure?

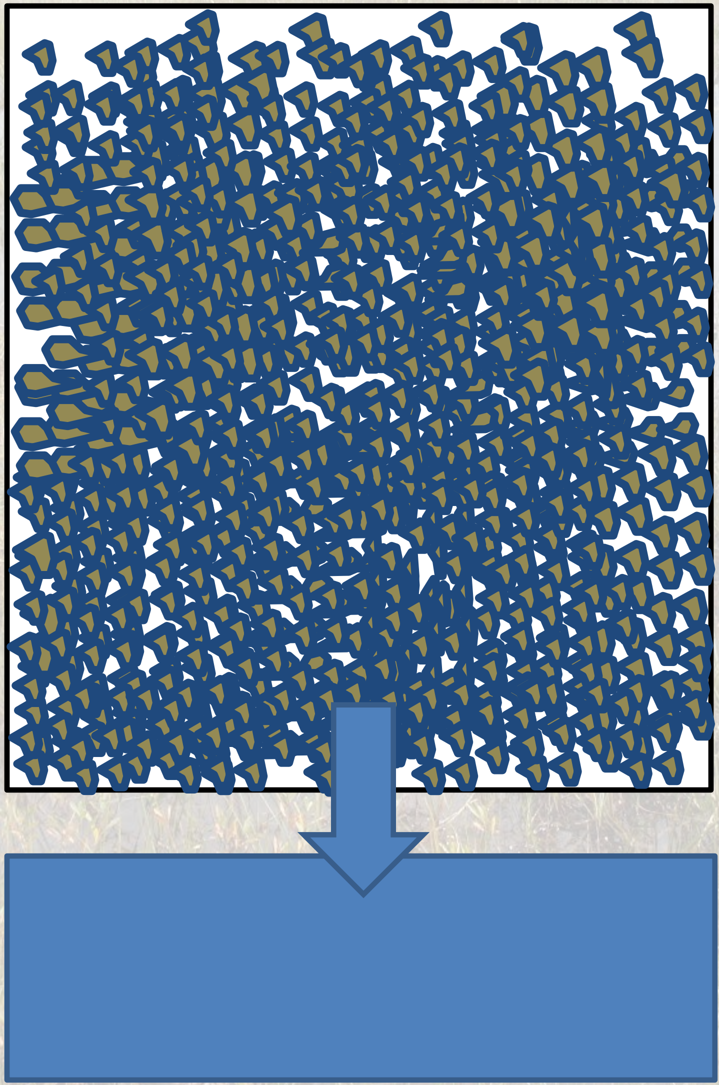


Water Budget

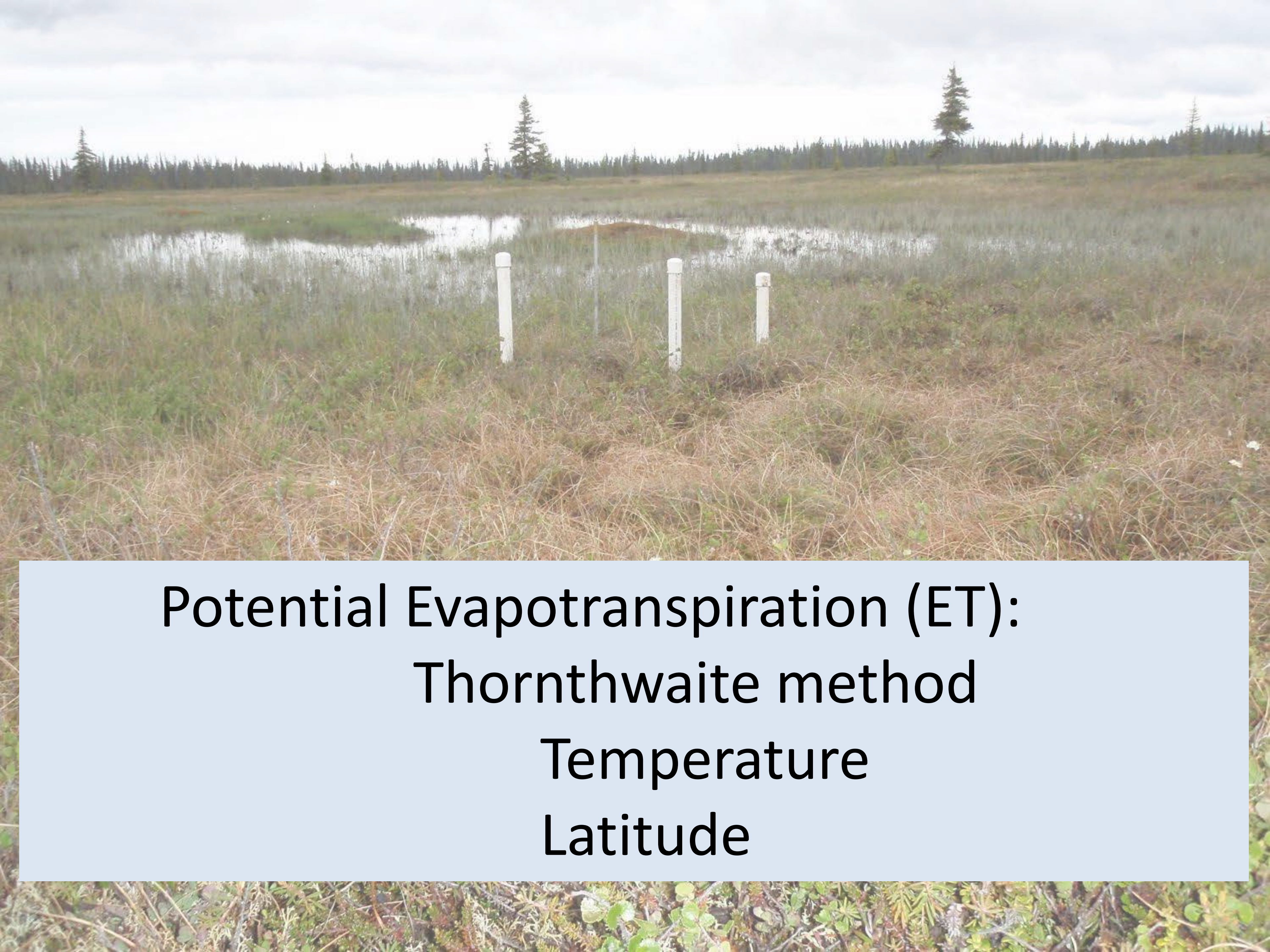
Water produced during drawdown?



Water Produced during drawdown?



= Specific Yield (S_y)



Potential Evapotranspiration (ET):

Thornthwaite method

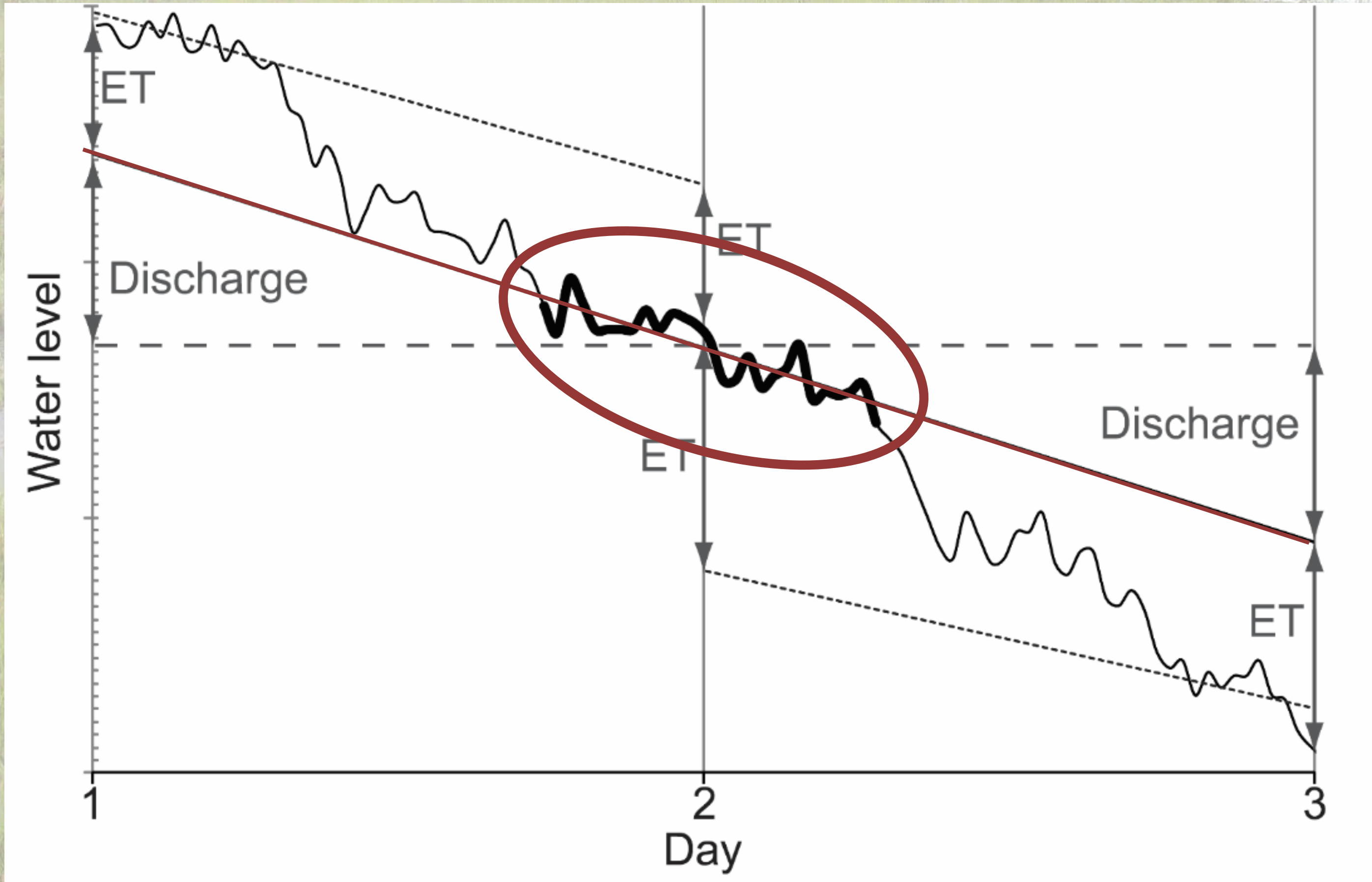
Temperature

Latitude

How to measure?

Diurnal Method

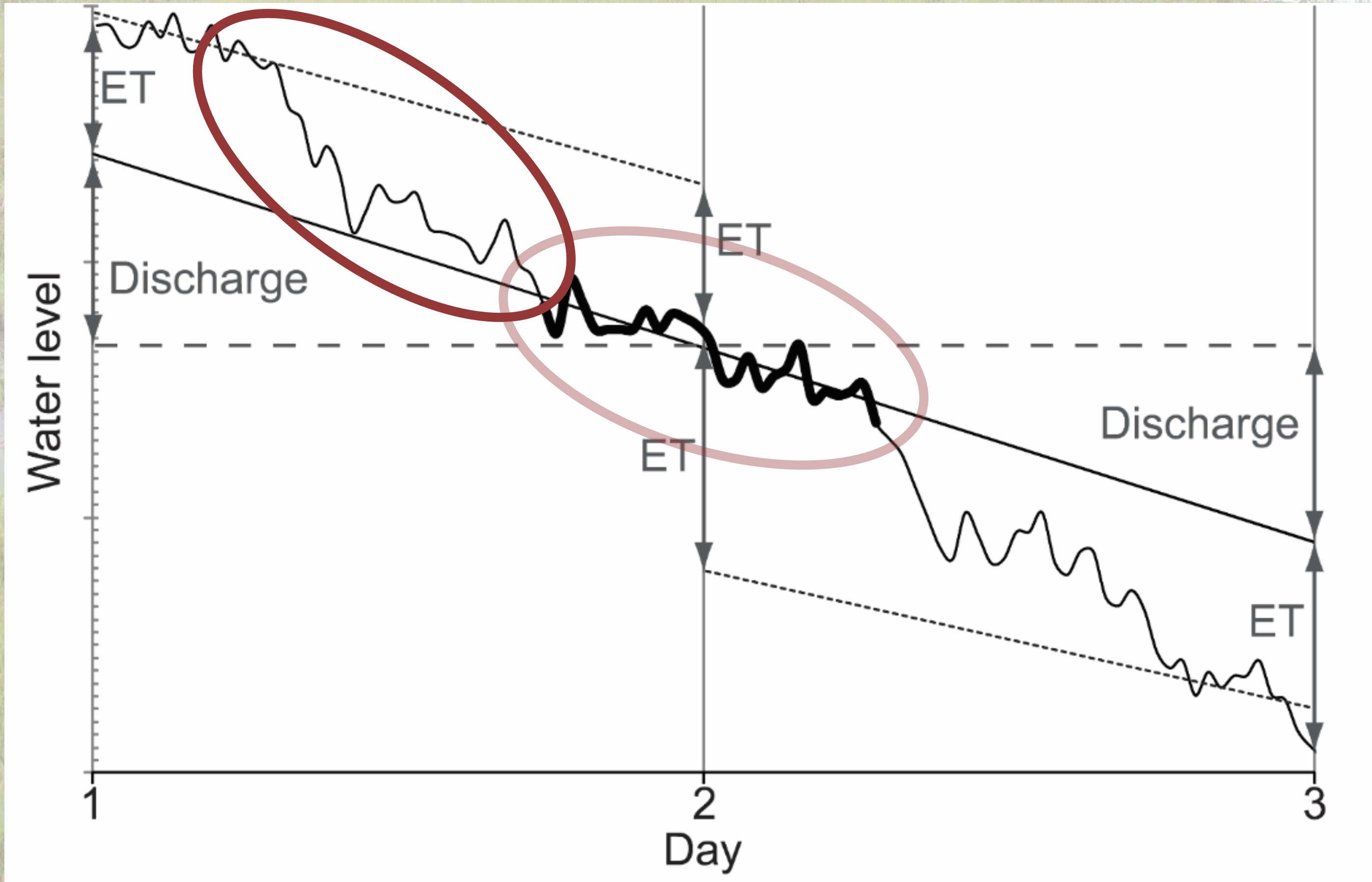
Night-time rate of decline



How to measure?

Diurnal Method

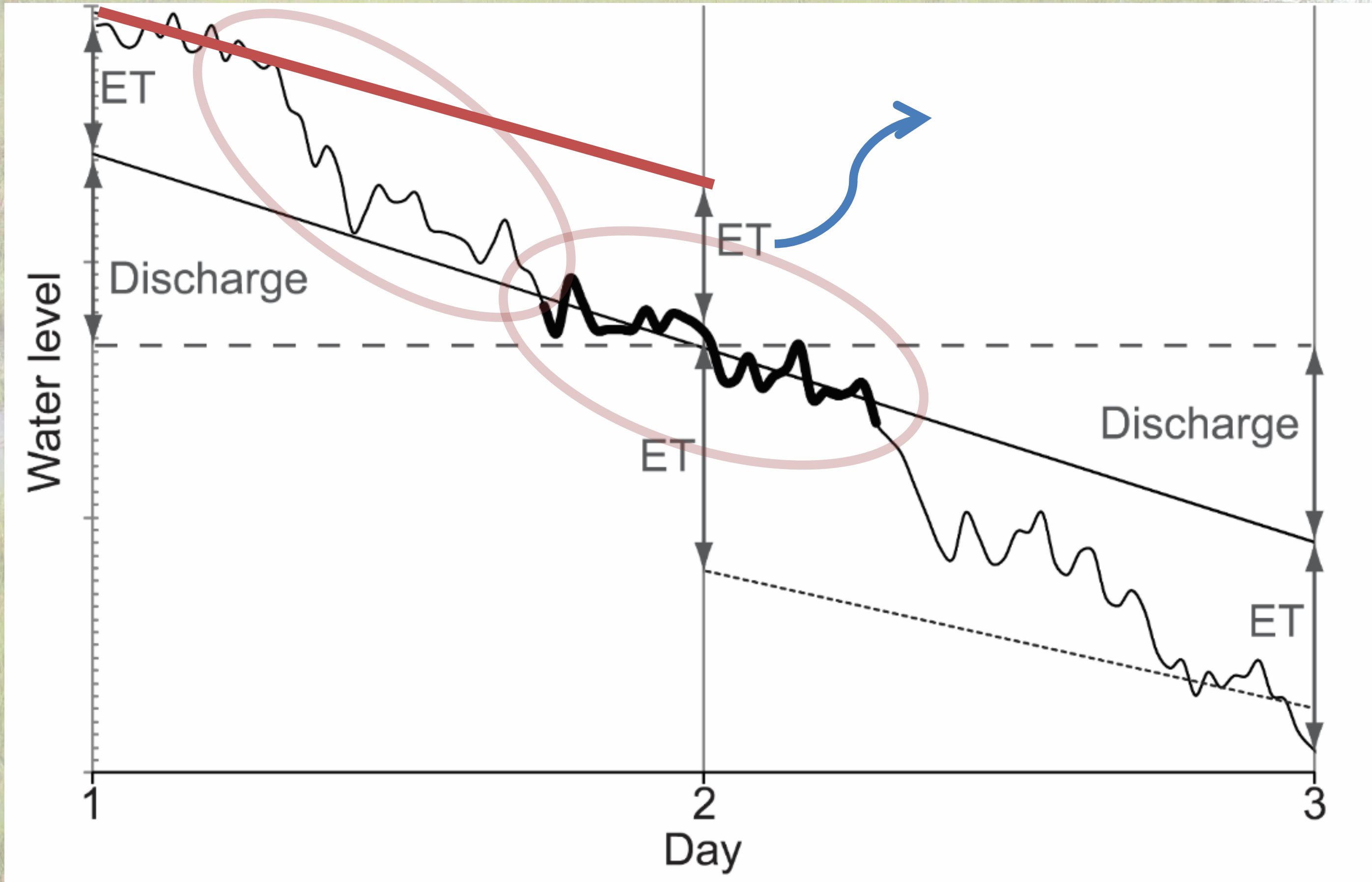
Day-time rate of decline



How to measure?

Diurnal Method

Difference = ET



Surplus Remaining For Stream Flow

Limpopo Creek

Actual water level decline (228mm/8d)
Area of similar peatlands in watershed

Actual dry-period flow (0.06 m^3s^{-1})

Amount Remaining For Stream Flow

(Actual dry-period flow = 0.06 m^3s^{-1})

		Specific Yield			
ϕ		**0.45**	**.14**	**0.10**	**0.05**
Thornthwaite	0.8	0.259	0.080	0.060	0.029
	0.9	0.297	0.092	0.066	0.033
	0.131	0	0	0	0
Diurnal ET		0.108	0.033	0.024	0.012

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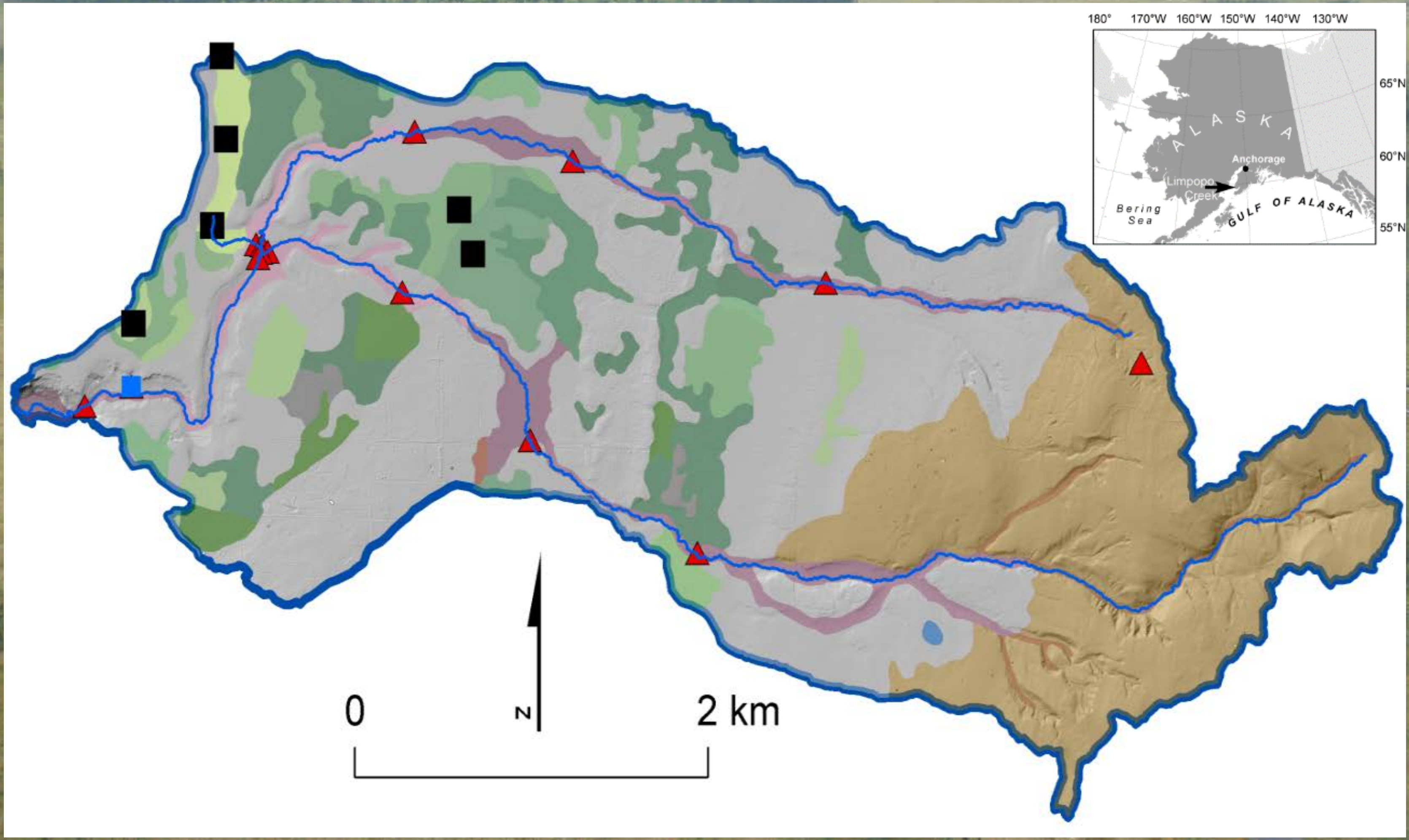
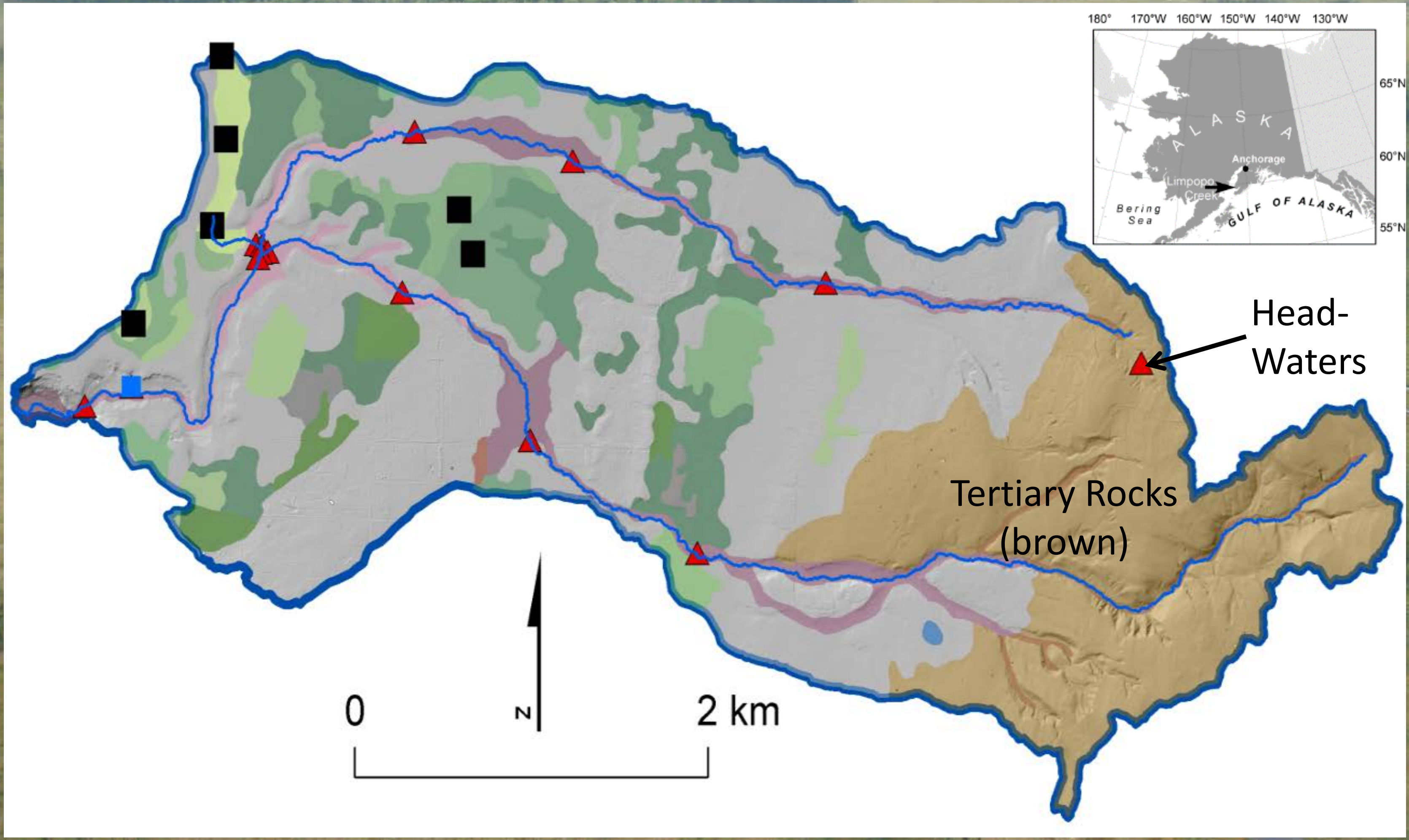
Possible that peatlands support flow during dry periods

Mixing Analysis

% contribution of end-members to stream flow



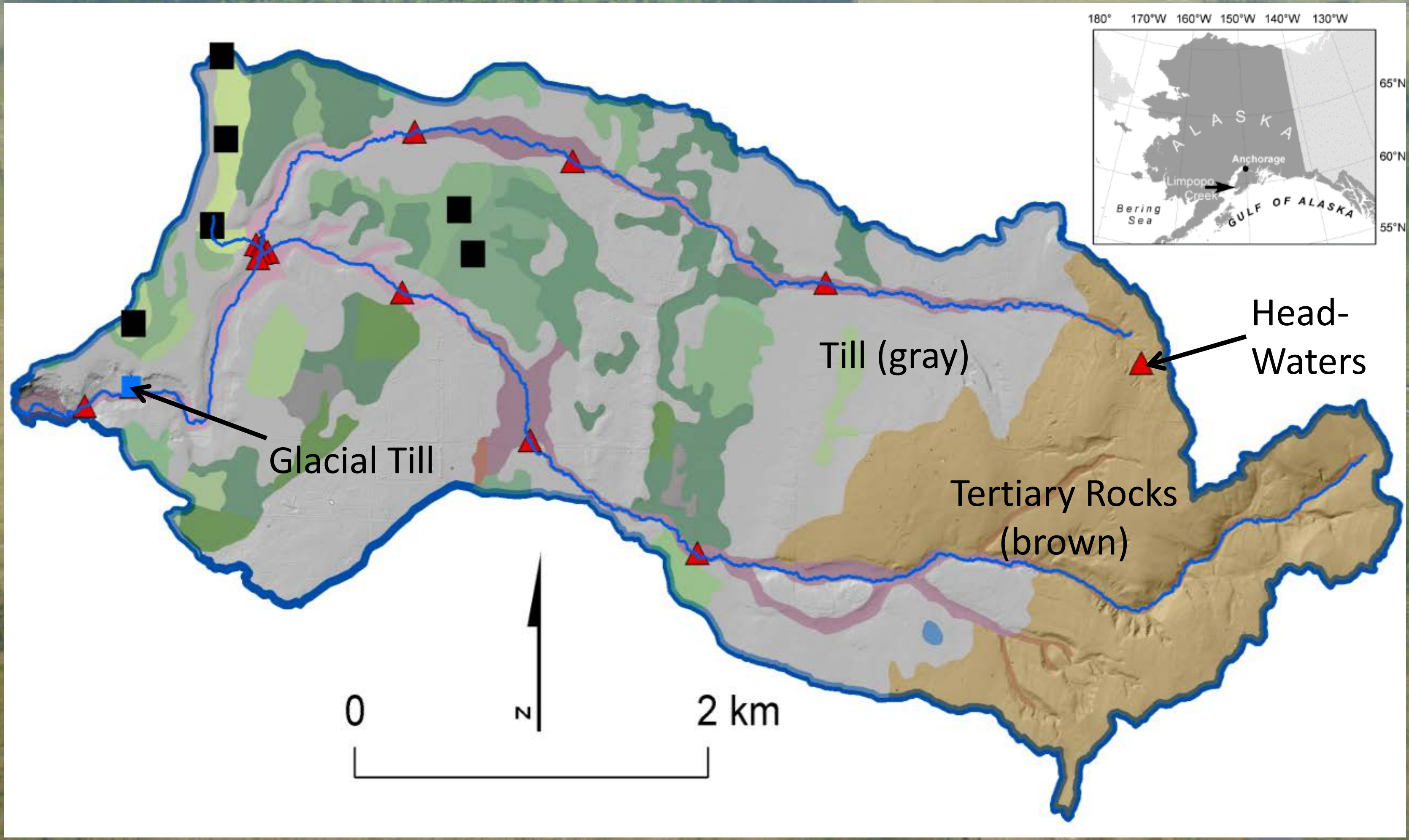
Mixing Analysis



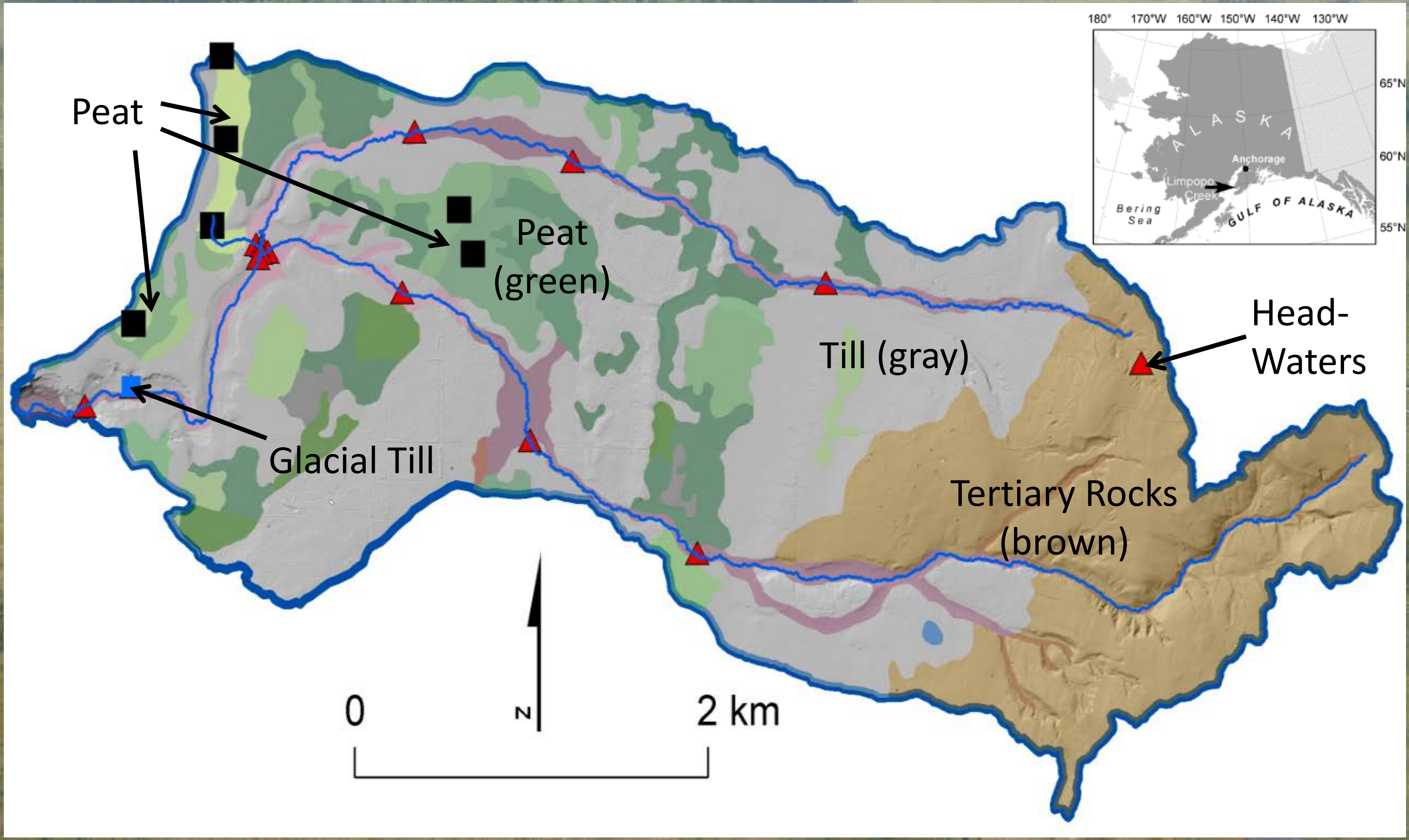
Head-Waters

Tertiary Rocks (brown)

Mixing Analysis



Mixing Analysis



Peat

Peat (green)

Glacial Till

Till (gray)

Head-Waters

Tertiary Rocks (brown)

Mixing Analysis

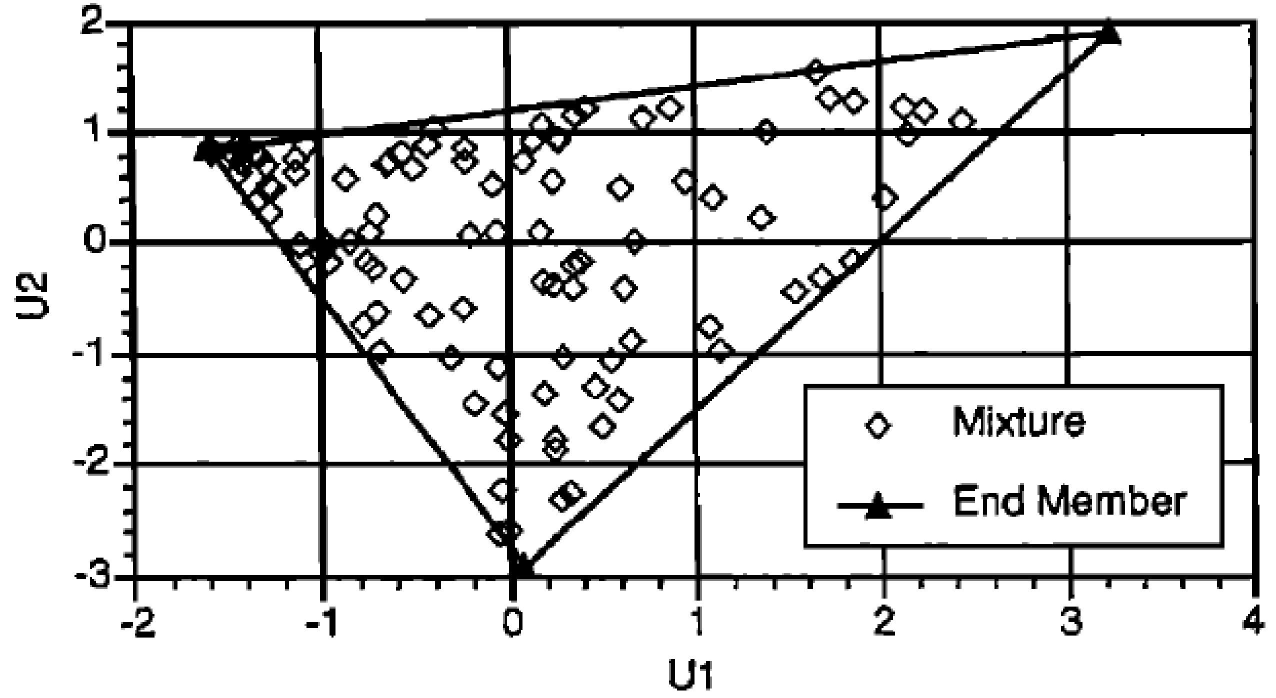
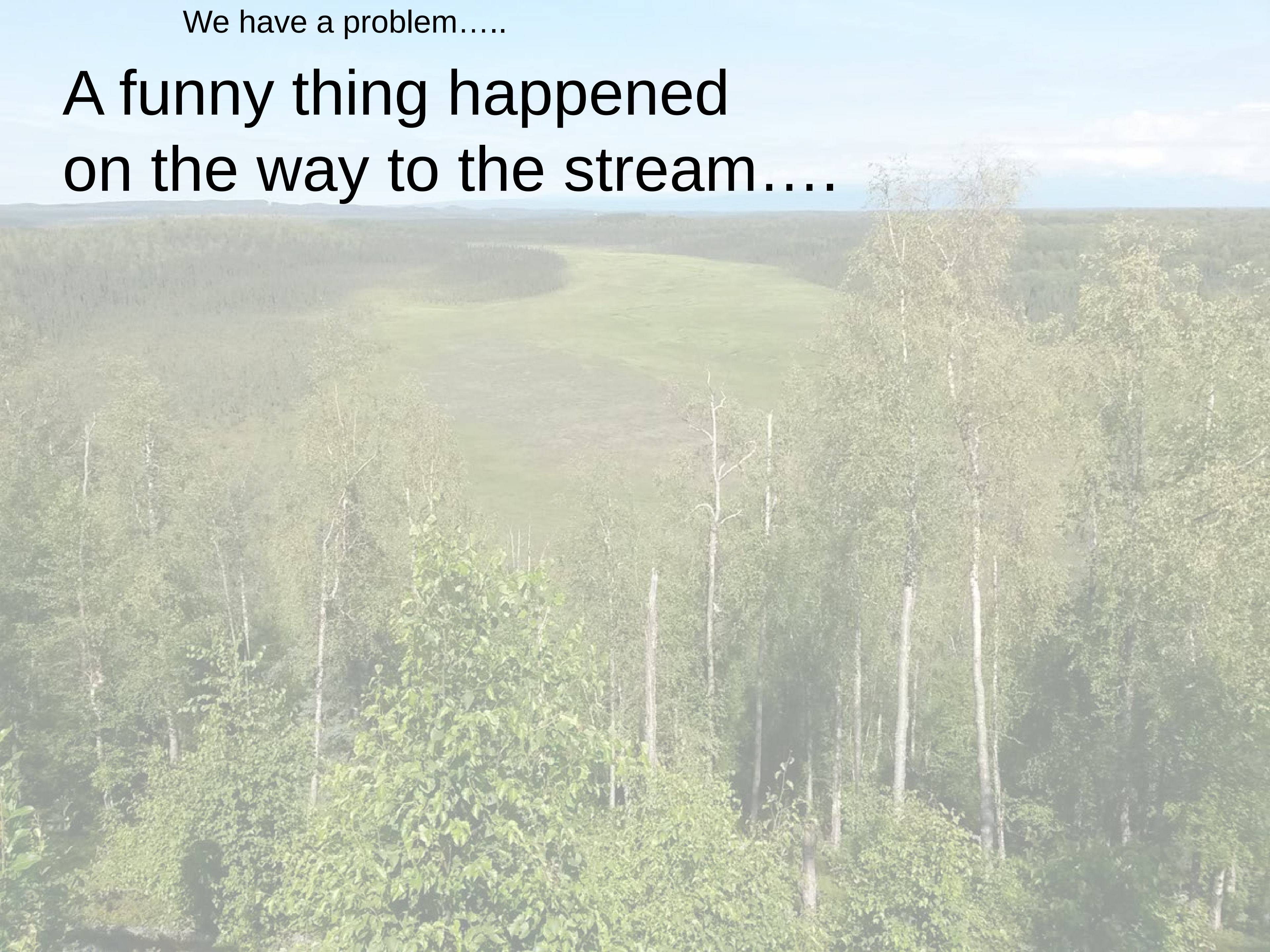


Fig. 3. Artificial data with pure end-members in *U* space defined by the correlation matrix.

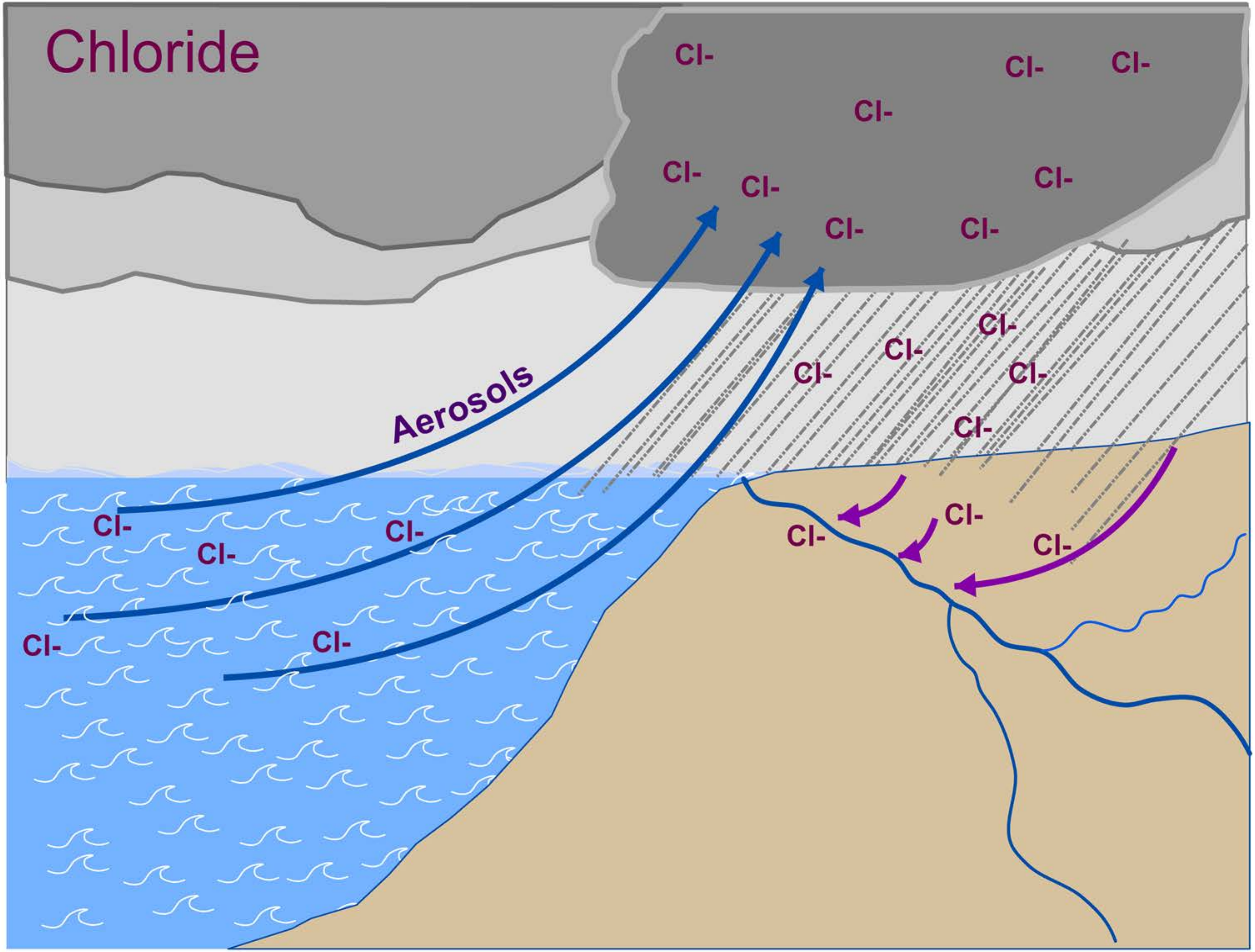
FROM:
Christophersen N, Hooper RP 1992. Multivariate analysis of stream water chemical data: The use of principal components analysis for the end-member mixing problem. *Water Resources Research* 28, 99-107. DOI: 10.1029/91wr02518.

We have a problem…..

A funny thing happened on the way to the stream….



Chloride


Cl-
Cl-
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Aerosols
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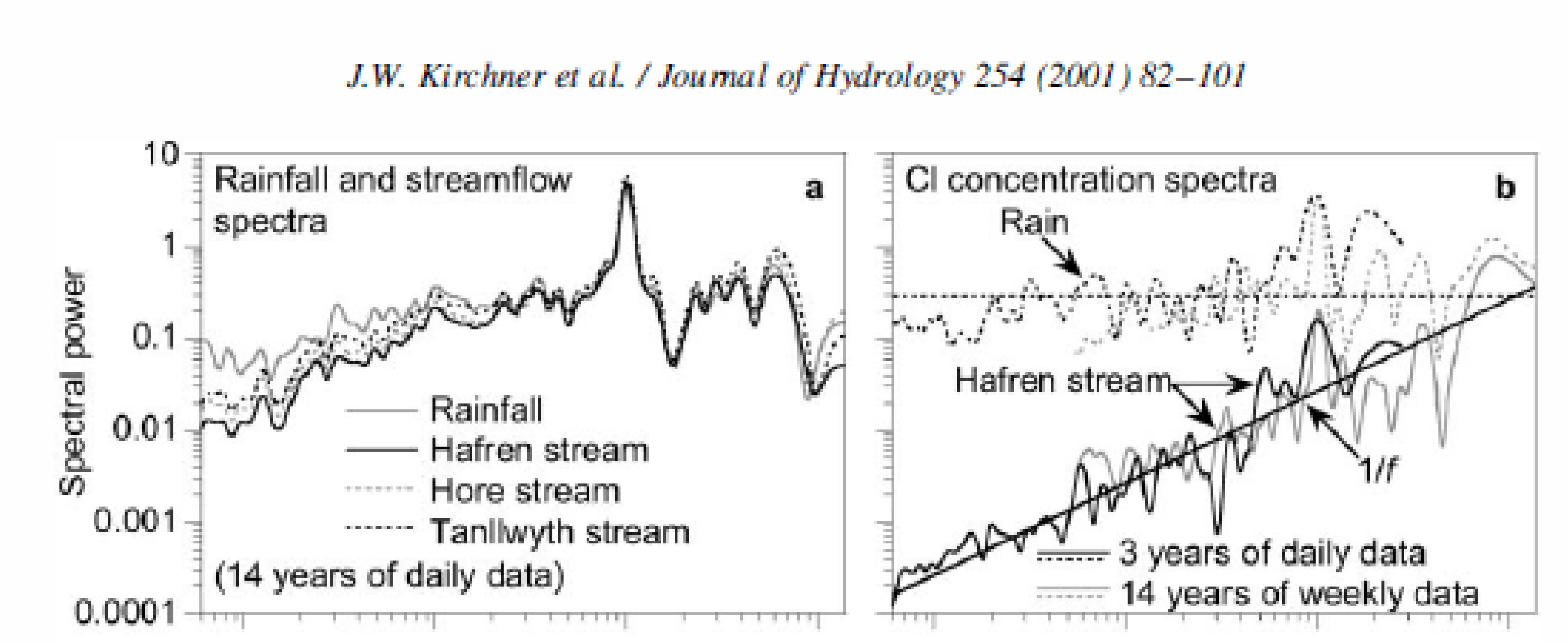
Flow averages over time
Chloride in rain averages over time
Chloride in stream water does not average


J.W. Kirchner et al. / Journal of Hydrology 254 (2001) 82–101

Amount of rainfall
or streamflow

Chloride in rainfall
or stream water

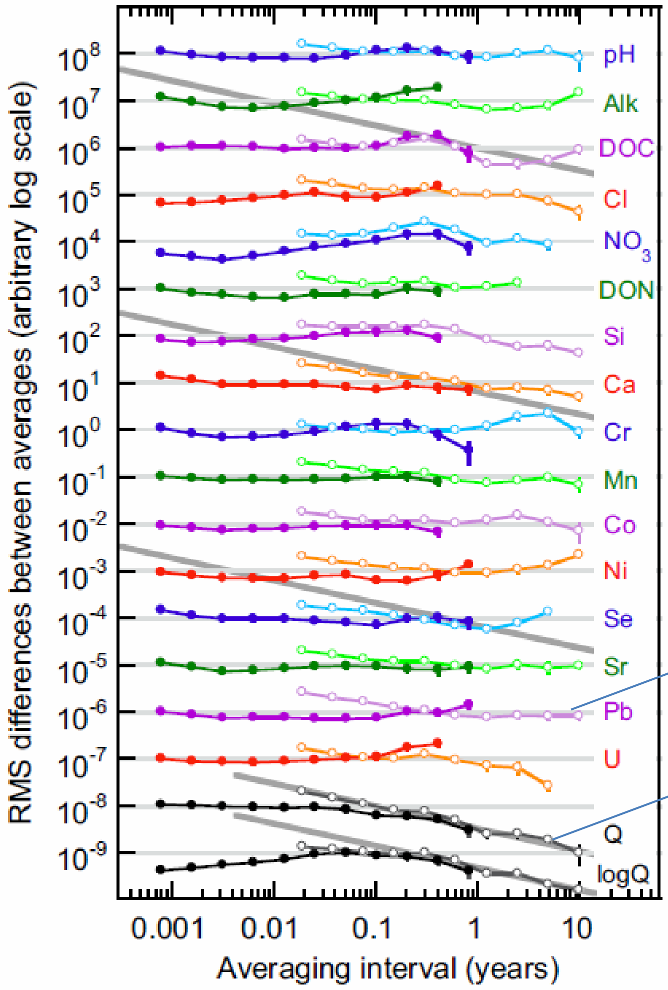


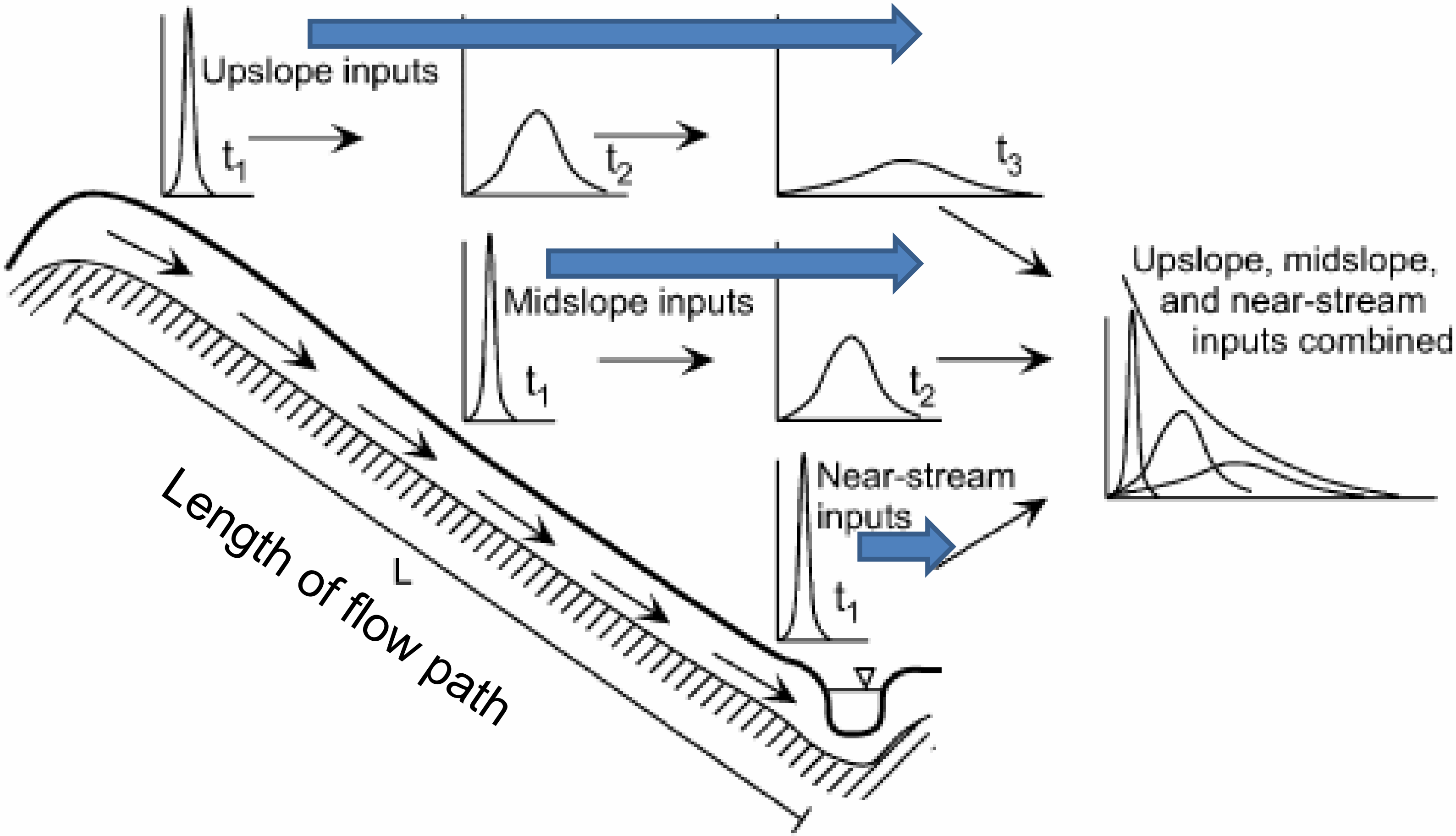
Fig. 4. Non–self-averaging behavior in water quality time series, illustrated by rms differences between successive mean concentrations of selected solutes in 7-h and weekly samples of Upper Hafren streamwater (solid and open symbols, respectively) averaged over intervals ranging from 7 h to 5–10 y. Error bars show SEs. Thin gray reference lines show trends for non–self-averaging behavior, in which averages over longer and longer time scales do not converge. Heavy gray lines show the slope of −0.5 predicted by the central limit theorem for self-averaging time series. The solutes generally plot as horizontal lines, indicating non–self-averaging behavior. In contrast, stream discharge and its logarithmic transform both follow the self-averaging behavior indicated by the heavy gray lines, for time scales longer than ~0.1 y. Individual solutes are shifted by arbitrary factors so they can be plotted together. Plots for all 45 solutes and both sampling sites are shown in *SI Appendix*, Fig. S10.

NOT Self-averaging over time: Lead (or almost everything but streamflow)

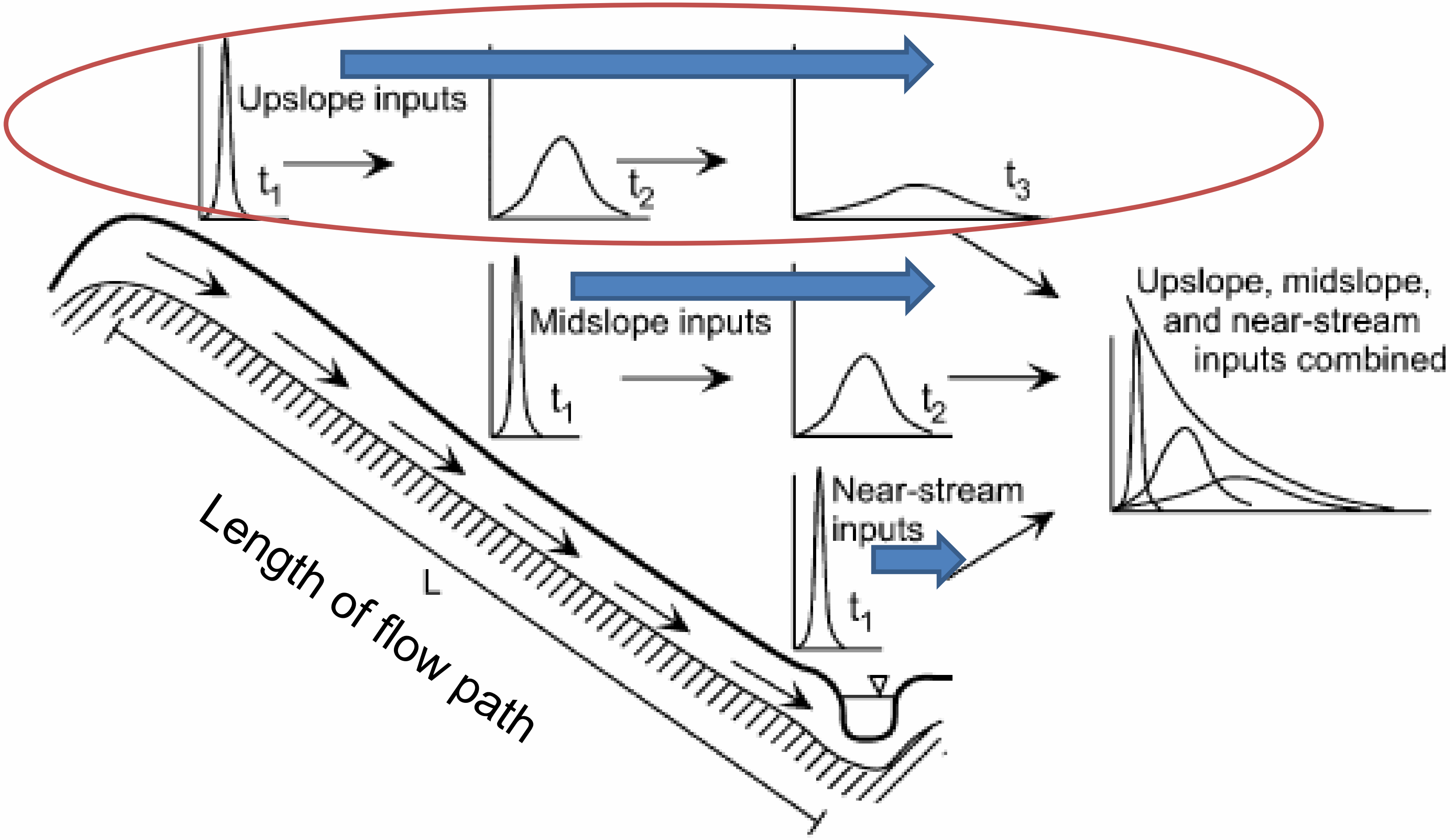
Self-averaging over time: streamflow

From: Kirchner, J.W., and Neal, C., 2013. Universal fractal scaling in stream chemistry and its implications for solute transport and water quality trend detection. Proceedings of the National Academy of Sciences 110, 122213-122218

J.W. Kirchner et al. / Journal of Hydrology 254 (2001) 82–101

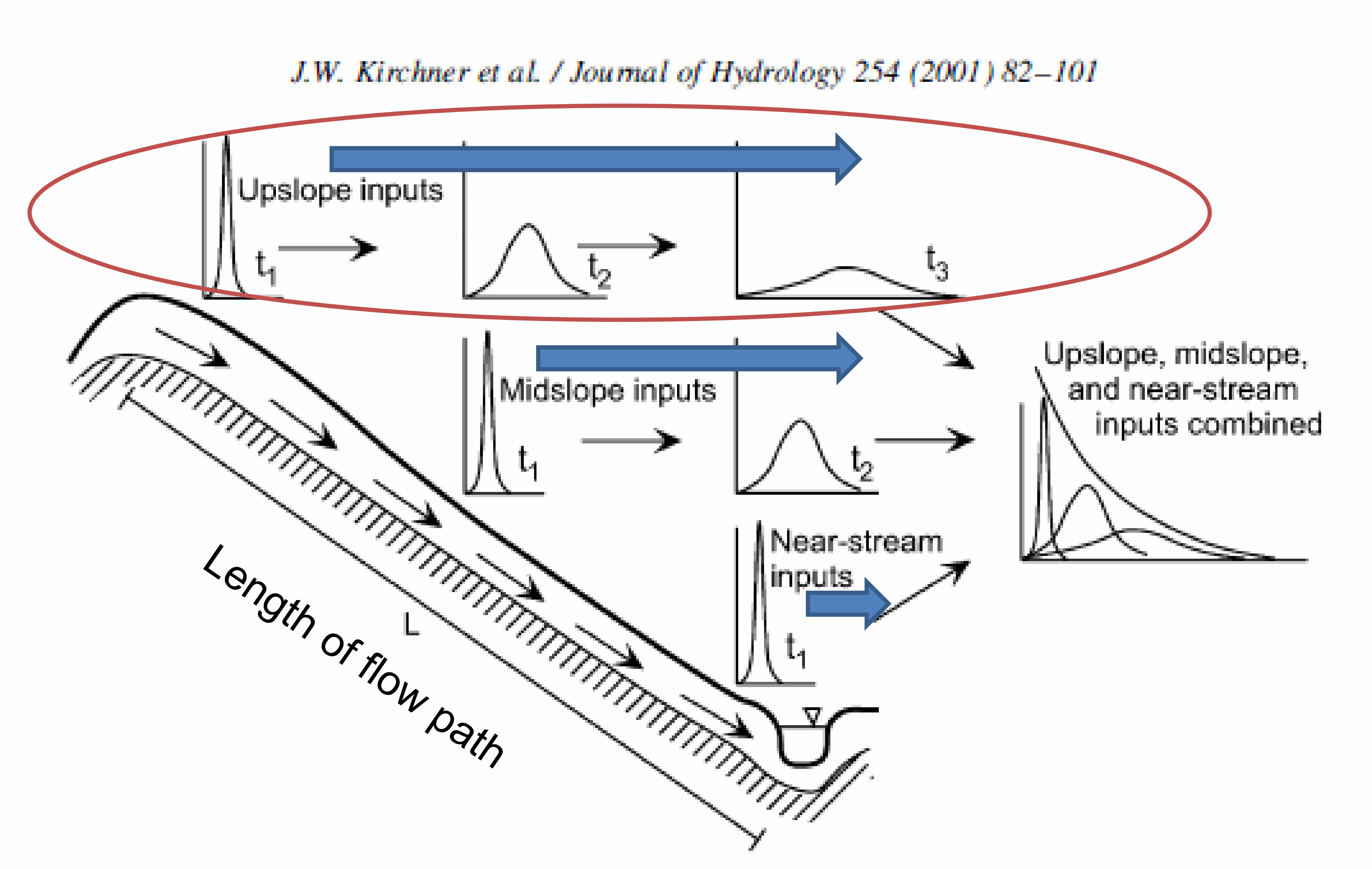


J.W. Kirchner et al. / Journal of Hydrology 254 (2001) 82–101

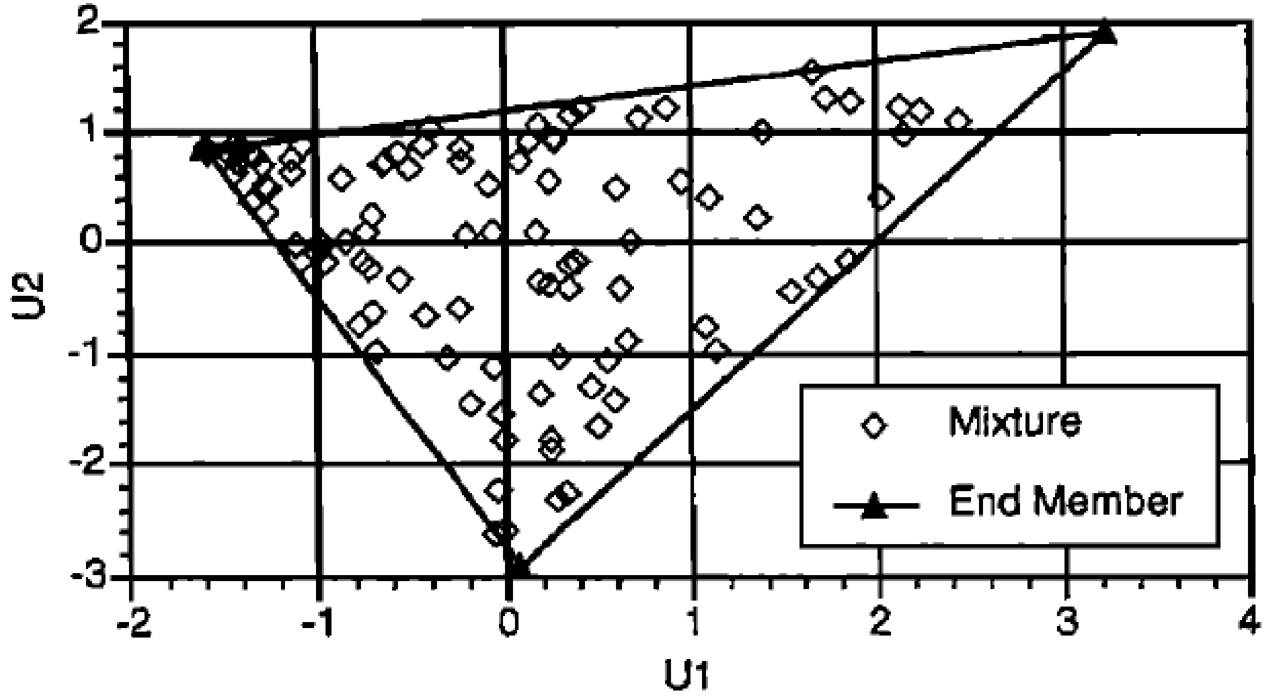


Length of flow path

Watershed acts as a “fractal filter”



Mixing Analysis



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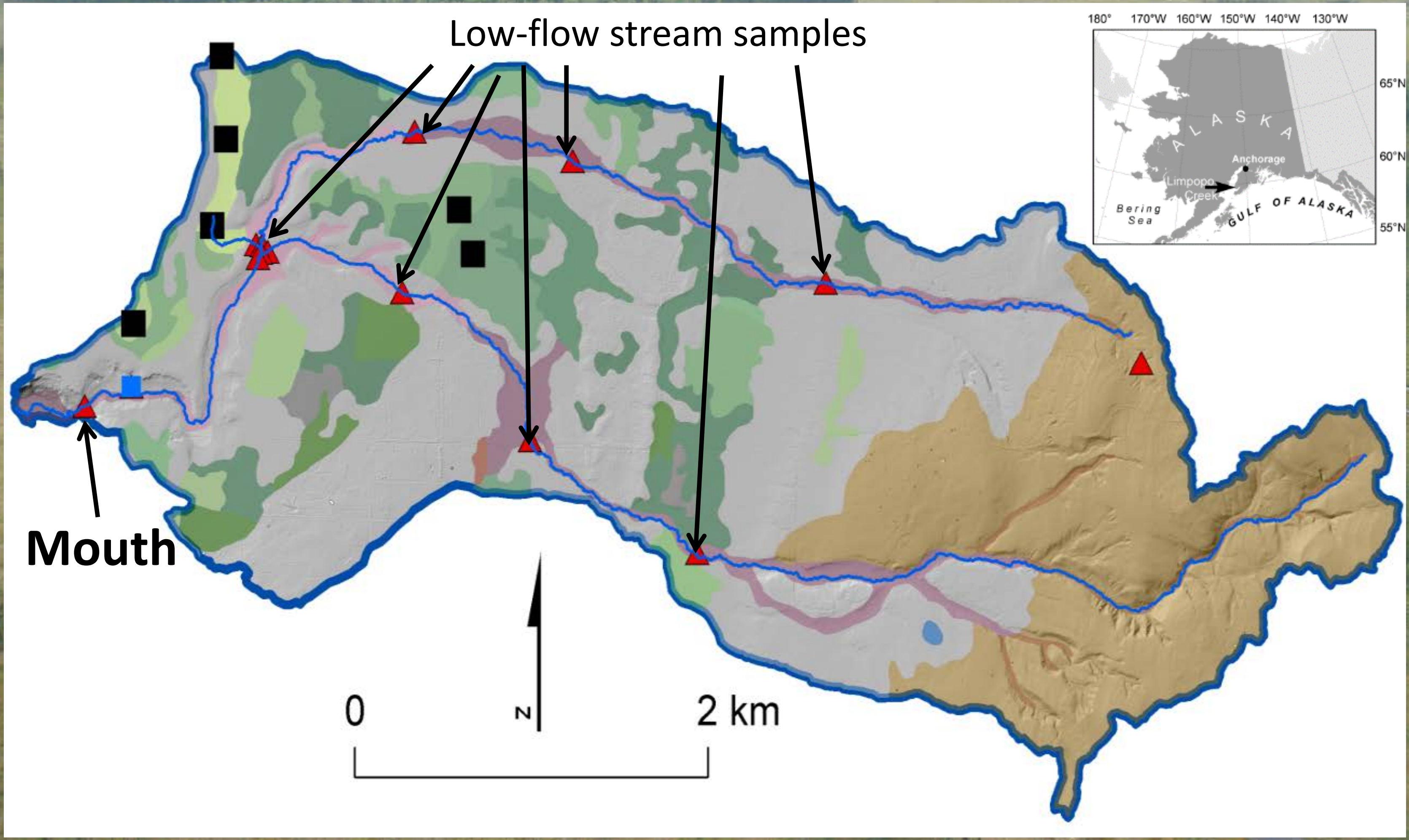
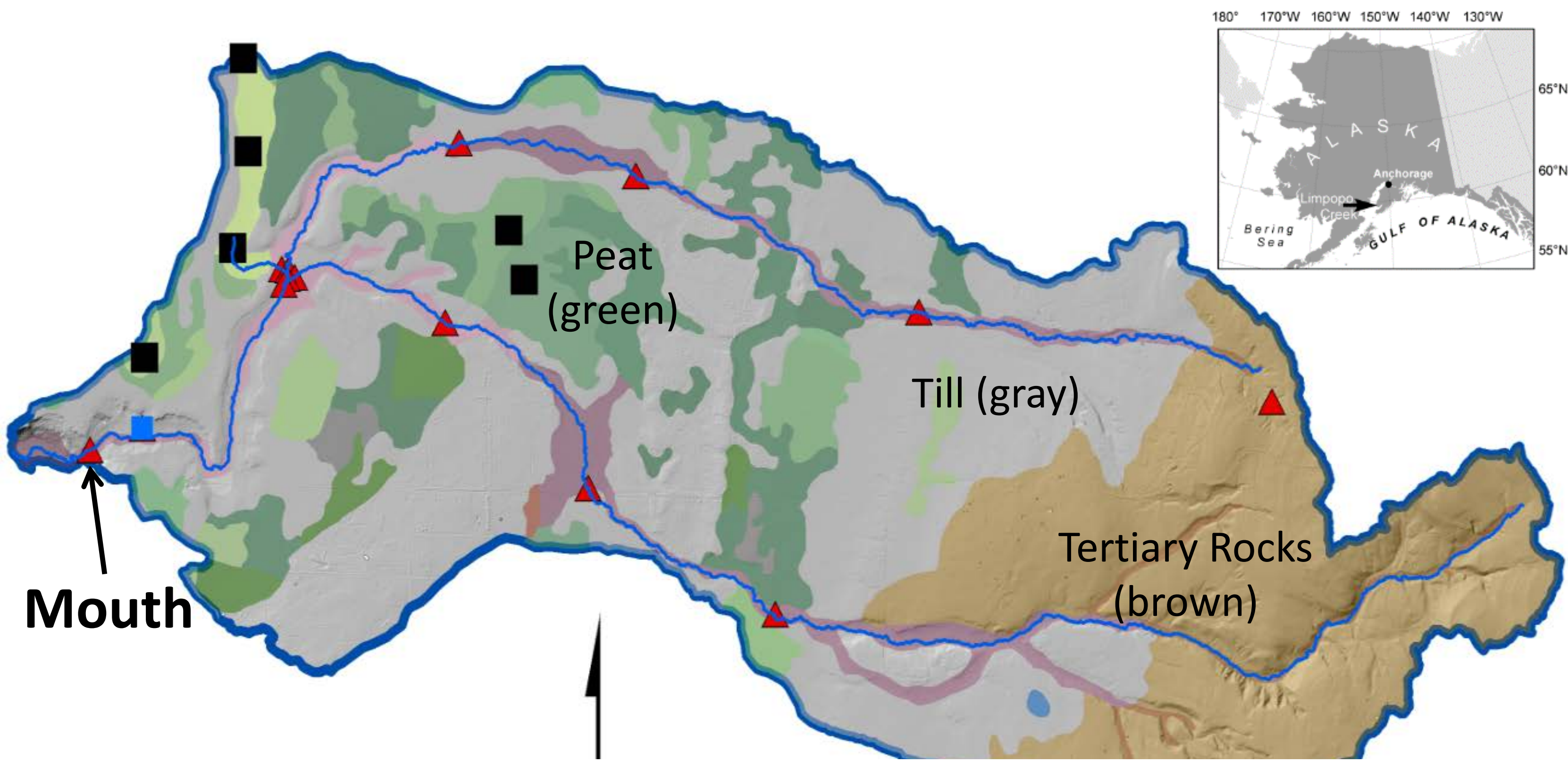


Low-flow stream samples

Mouth

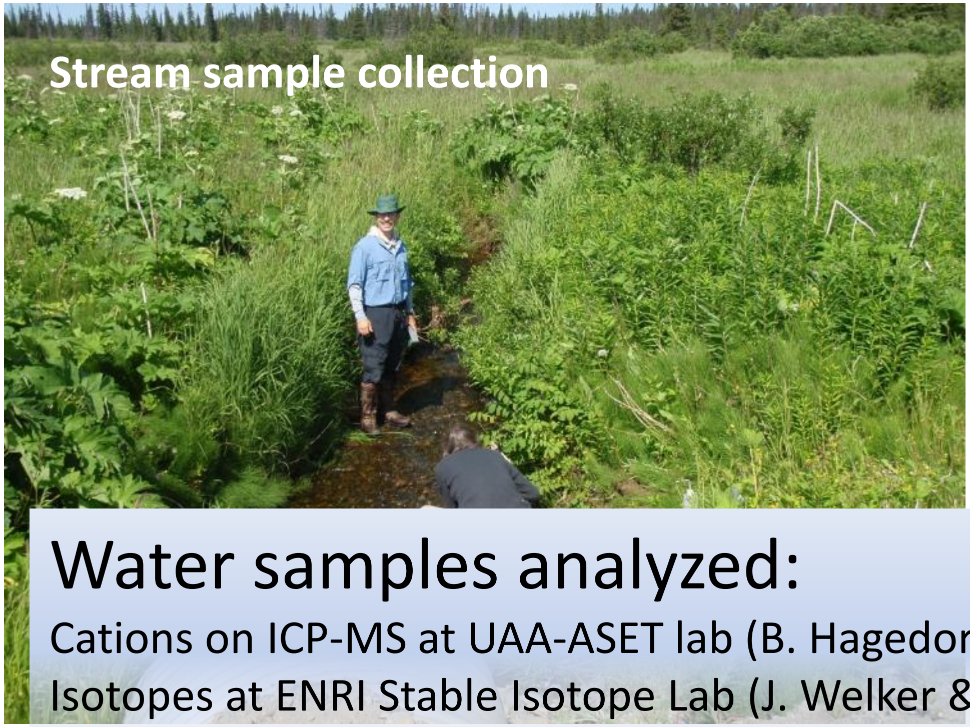
Mixing Model



Stream Water at Mouth = % each end-member


Stream sample collection


Peat sample collection



Stream sample collection

Peat sample collection

Water samples analyzed:

Cations on ICP-MS at UAA-ASET lab (B. Hagedorn)

Isotopes at ENRI Stable Isotope Lab (J. Welker & M. Rogers)

Anions at EPA MED lab, Duluth, MN (M. Moffett, L. Anderson)

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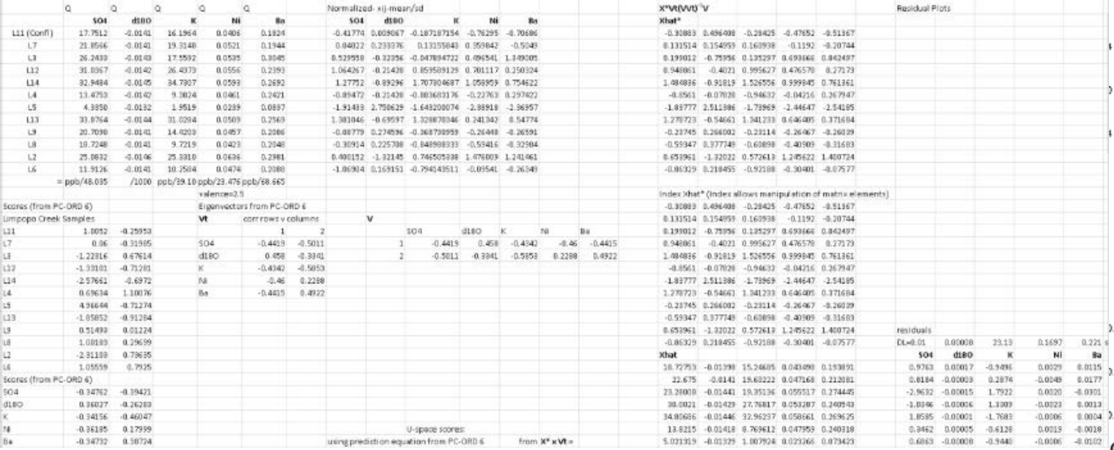
PCA: EMMA procedures

-Hooper 2003



	Q SO4	Q d18O	Q K	Q Ni	Q Ba
L11 (Confl)	17.7512	-0.0141	16.1964	0.0406	0.1824
L7	21.8566	-0.0141	19.3148	0.0521	0.1944
L3	26.2433	-0.0143	17.5592	0.0535	0.3045
L12	31.0367	-0.0142	26.4373	0.0556	0.2393
L14	32.9484	-0.0145	34.7307	0.0593	0.2692
L4	13.4753	-0.0142	9.3824	0.0461	0.2421
L5	4.3850	-0.0132	1.9519	0.0239	0.0887
L13	33.0764	-0.0144	31.0294	0.0509	0.2569
L9	20.7090	-0.0141	14.4203	0.0457	0.2086
L8	18.7248	-0.0141	9.7219	0.0423	0.2048
L2	25.0832	-0.0146	25.3310	0.0636	0.2981
L6	11.9126	-0.0141	10.2504	0.0474	0.2088
	= ppb/48.035	/1000	ppb/39.10	ppb/23.476	ppb/68.665
				valence=2.5	

Normalized- xij-mean/sd

SO4	d18O	K	Ni	Ba
-0.41774	0.009067	-0.187187154	-0.76295	-0.70686
0.04022	0.233376	0.13155843	0.359842	-0.5049
0.529558	-0.32256	-0.047894722	0.496541	1.349005
1.064267	-0.21428	0.859589129	0.701117	0.250324
1.27752	-0.89296	1.707804687	1.058959	0.754622
-0.89472	-0.21428	-0.883683176	-0.22763	0.297422
-1.91433	2.750629	-1.643208074	-2.88918	-2.86957
1.381046	-0.69597	1.328878346	0.241342	0.54774
-0.08779	0.274596	-0.368730959	-0.26448	-0.26591
-0.30914	0.225708	-0.848988333	-0.59416	-0.32984
0.400152	-1.32145	0.746505338	1.476009	1.241461
-1.06904	0.169151	-0.794143511	-0.09541	-0.26349

Scores (from PC-ORD 6)

Limpopo Creek Samples

L11	1.0052	-0.25953
L7	0.06	-0.31985
L3	-1.22816	0.67614
L12	-1.33101	-0.71281
L14	-2.57661	-0.6972
L4	0.69634	1.10076
L5	4.96644	-0.71274
L13	-1.85852	-0.91284
L9	0.51493	0.01224
L8	1.00183	0.29699
L2	-2.31108	0.79635
L6	1.05559	0.7925

Scores (from PC-ORD 6)

SO4	-0.34762	-0.39421
d18O	0.36027	-0.26283
K	-0.34156	-0.46047
Ni	-0.36185	0.17999
Ba	-0.34732	0.38724

Eigenvectors from PC-ORD 6

Vt	corr rows v columns 1	2
SO4	-0.4419	-0.5011
d18O	0.458	-0.3341
K	-0.4342	-0.5853
Ni	-0.46	0.2288
Ba	-0.4415	0.4922

V

	SO4	d18O	K	Ni	Ba
1	-0.4419	0.458	-0.4342	-0.46	-0.4415
2	-0.5011	-0.3341	-0.5853	0.2288	0.4922

U-space scores:

using prediction equation from PC-ORD 6 from X* x Vt =

X*Vt(VVt)$^{-1}$V

Xhat*

-0.30883	0.496408	-0.28425	-0.47652	-0.51367
0.131514	0.154959	0.160938	-0.1192	-0.20744
0.190012	-0.75956	0.135297	0.693666	0.842497
0.948061	-0.4021	0.995627	0.476578	0.27173
1.484836	-0.91819	1.526556	0.999845	0.761361
-0.8561	-0.07028	-0.94632	-0.04216	0.267947
-1.83777	2.511386	-1.73969	-2.44647	-2.54185
1.270723	-0.54661	1.341233	0.646405	0.371684
-0.23745	0.266002	-0.23114	-0.26467	-0.26039
-0.59347	0.377749	-0.60898	-0.40909	-0.31683
0.653961	-1.32022	0.572613	1.245622	1.400724
-0.86329	0.218455	-0.92188	-0.30401	-0.07577

Index Xhat* (Index allows manipulation of matrix elements)

-0.30883	0.496408	-0.28425	-0.47652	-0.51367
0.131514	0.154959	0.160938	-0.1192	-0.20744
0.190012	-0.75956	0.135297	0.693666	0.842497
0.948061	-0.4021	0.995627	0.476578	0.27173
1.484836	-0.91819	1.526556	0.999845	0.761361
-0.8561	-0.07028	-0.94632	-0.04216	0.267947
-1.83777	2.511386	-1.73969	-2.44647	-2.54185
1.270723	-0.54661	1.341233	0.646405	0.371684
-0.23745	0.266002	-0.23114	-0.26467	-0.26039
-0.59347	0.377749	-0.60898	-0.40909	-0.31683
0.653961	-1.32022	0.572613	1.245622	1.400724
-0.86329	0.218455	-0.92188	-0.30401	-0.07577

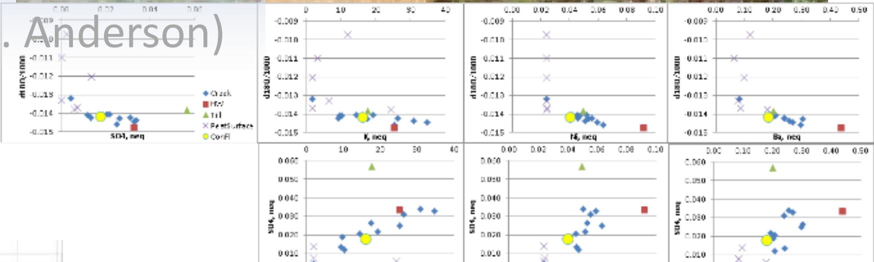
Xhat

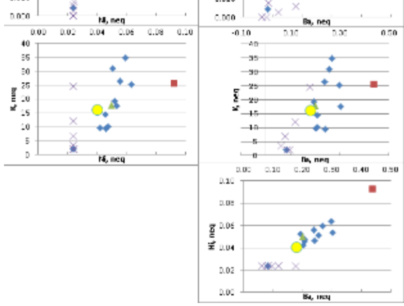
18.72753	-0.01398	15.24605	0.043498	0.193891
22.675	-0.0141	19.60222	0.047168	0.212081
23.28008	-0.01441	19.35136	0.055517	0.274445
30.0021	-0.01429	27.76817	0.053287	0.240543
34.80686	-0.01446	32.96237	0.058661	0.269625
13.8215	-0.01418	8.769612	0.047959	0.240318
5.021319	-0.01329	1.007924	0.023266	0.073423

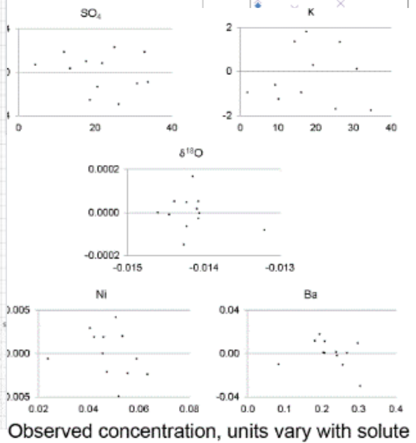
Residual Plots

residuals

DL=0.01	0.00008	23.19	0.1697	0.221
SO4	d18O	K	Ni	Ba
0.9763	0.00017	-0.9496	0.0029	0.0115
0.8184	-0.00003	0.2874	-0.0049	0.0177
-2.9632	-0.00015	1.7922	0.0020	-0.0301
-1.0046	-0.00006	1.3309	-0.0023	0.0013
1.0585	-0.00001	-1.7683	-0.0006	0.0004
0.3462	0.00005	-0.6128	0.0019	-0.0018
0.6863	-0.00008	-0.9440	-0.0006	-0.0102





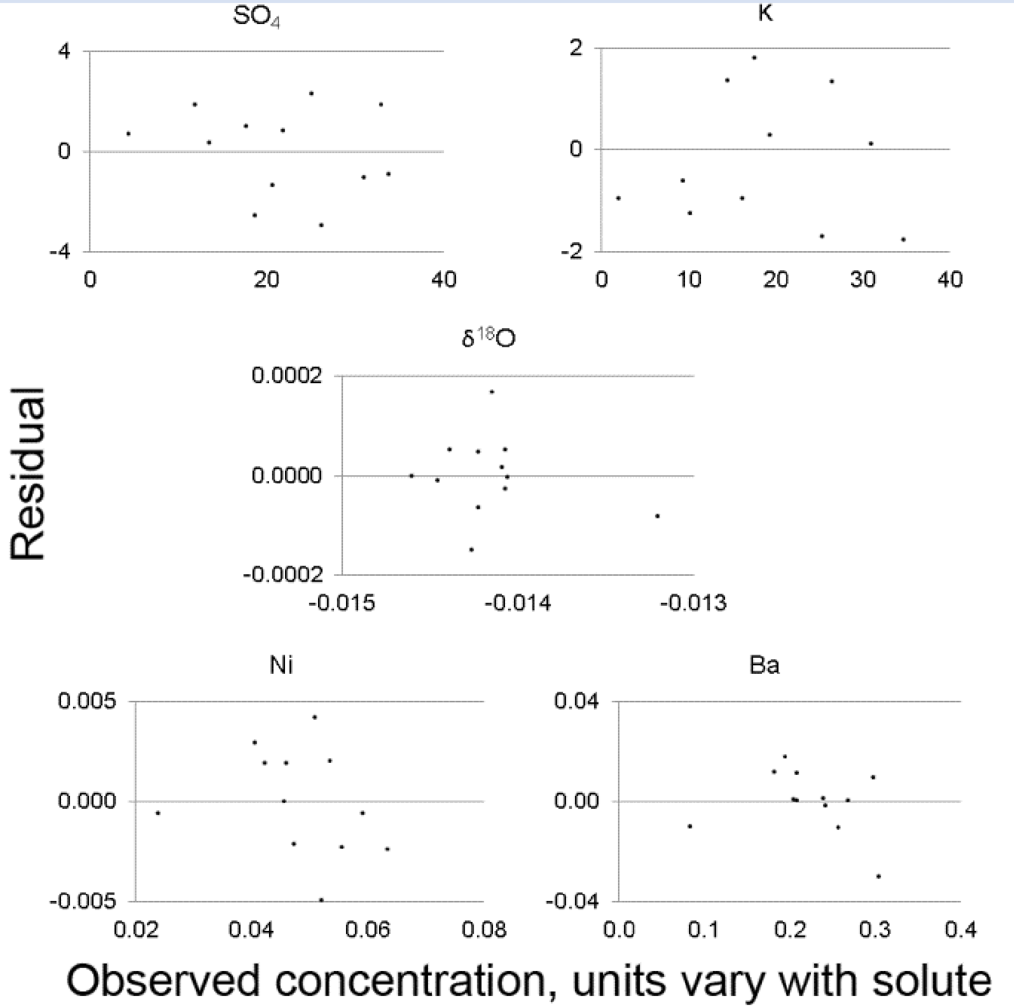


Observed concentration, units vary with solute

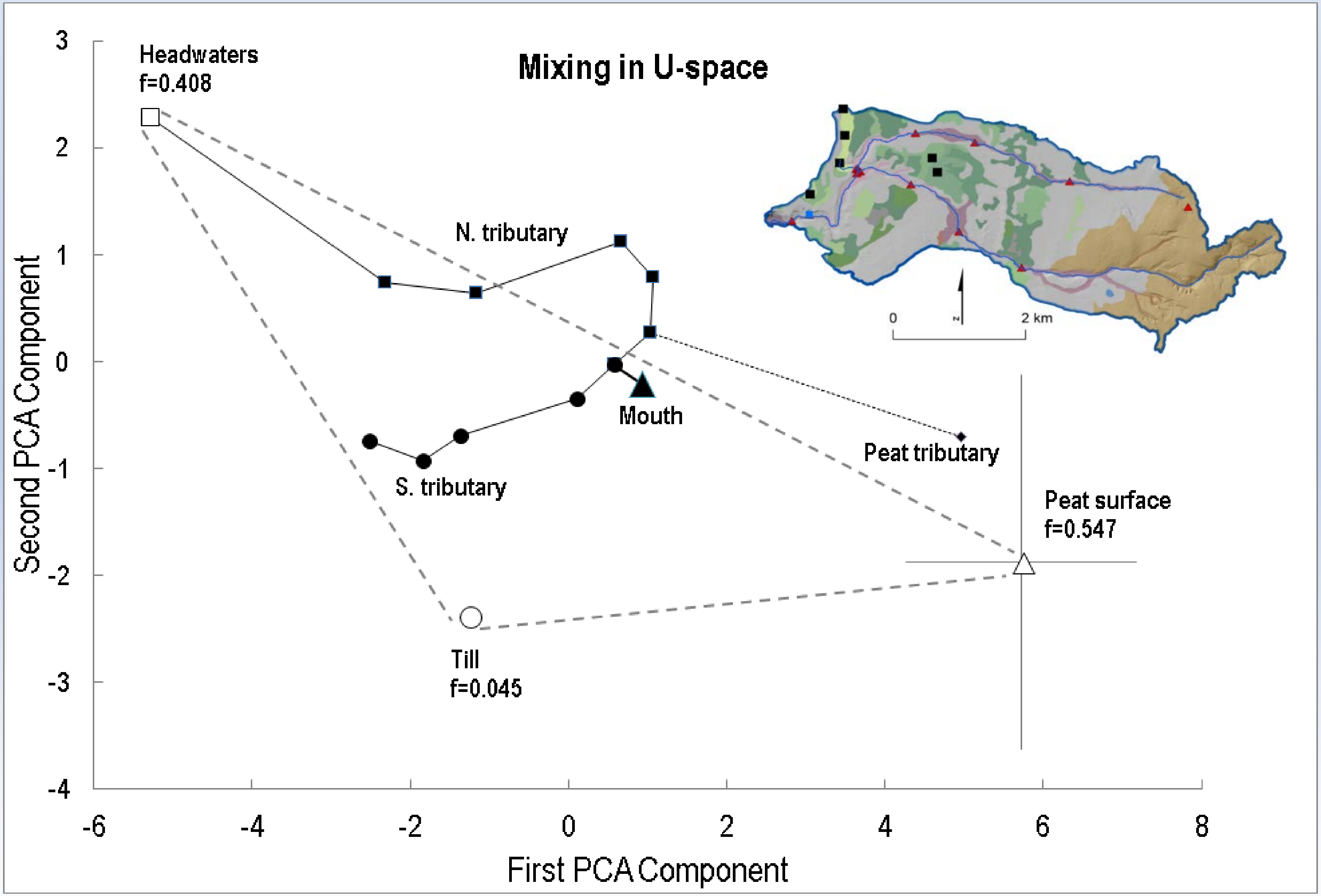
End-Member Mixing Analysis:

Tracers mix conservatively
All end-members identified
End-members sufficiently different
Mixing is hydrologically possible
End-members of fixed composition

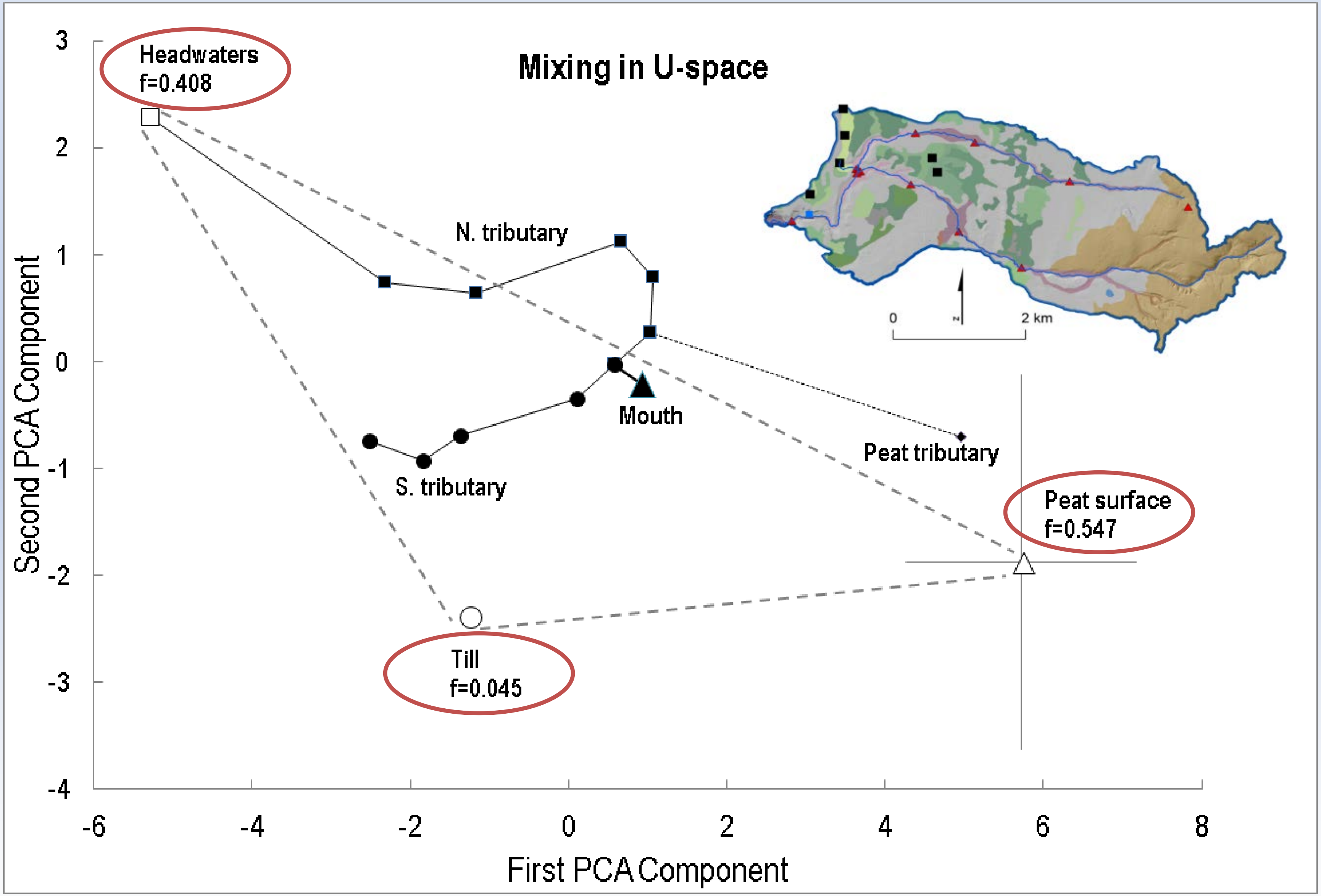
5 tracers: SO_4, K, $\delta^{18}O$, Ni, Ba



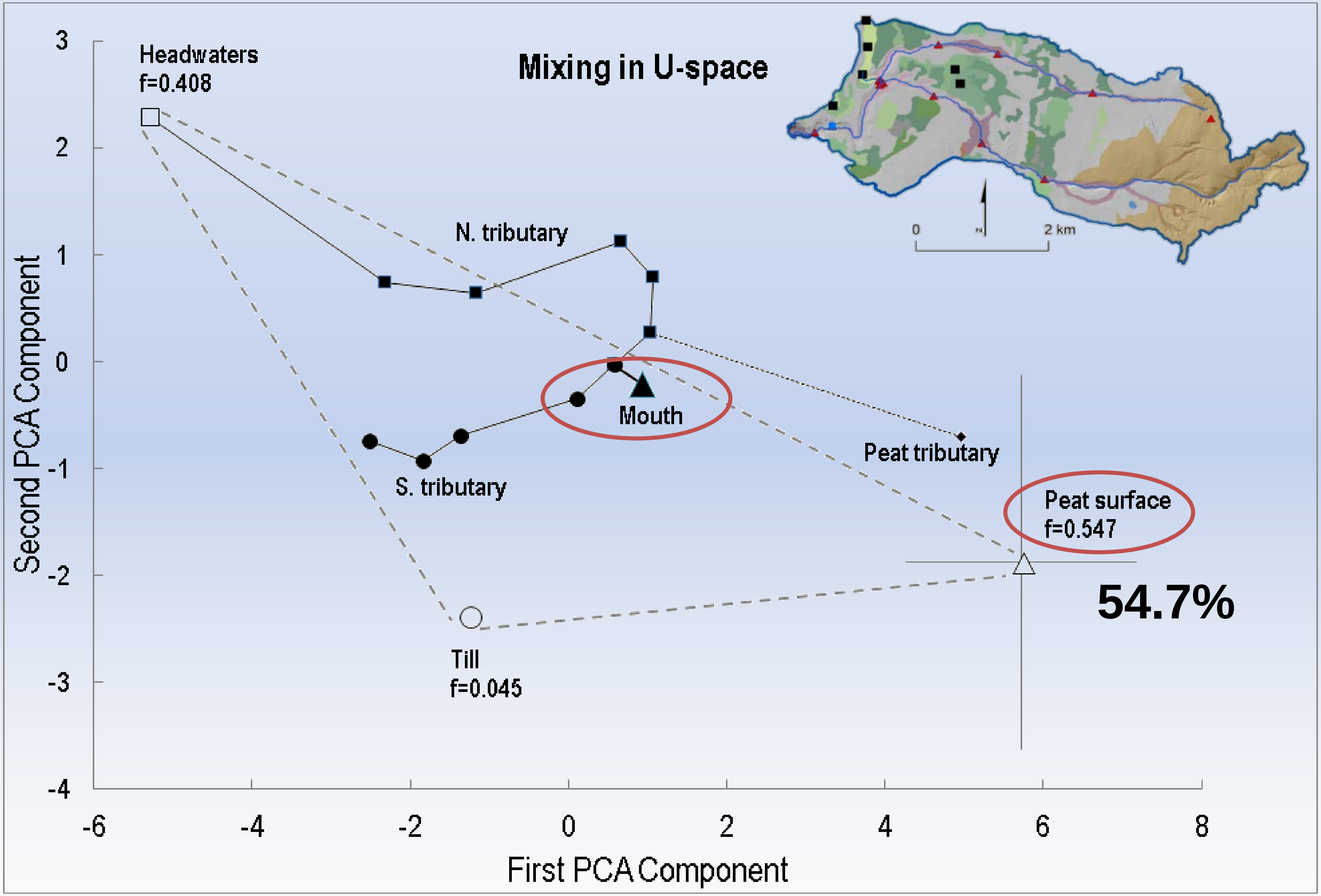
3 End-member model



3 End-member model

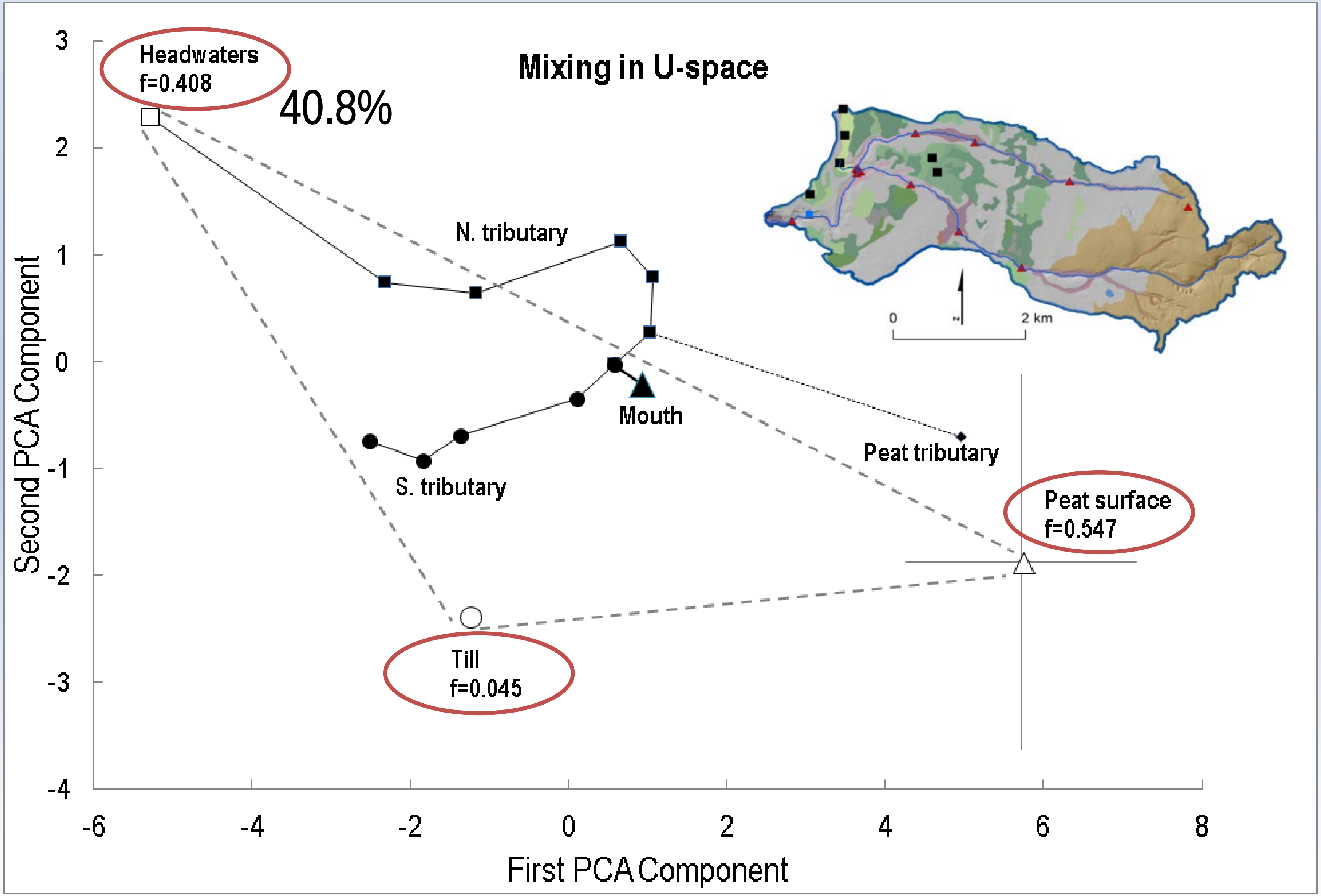


3 End-member model

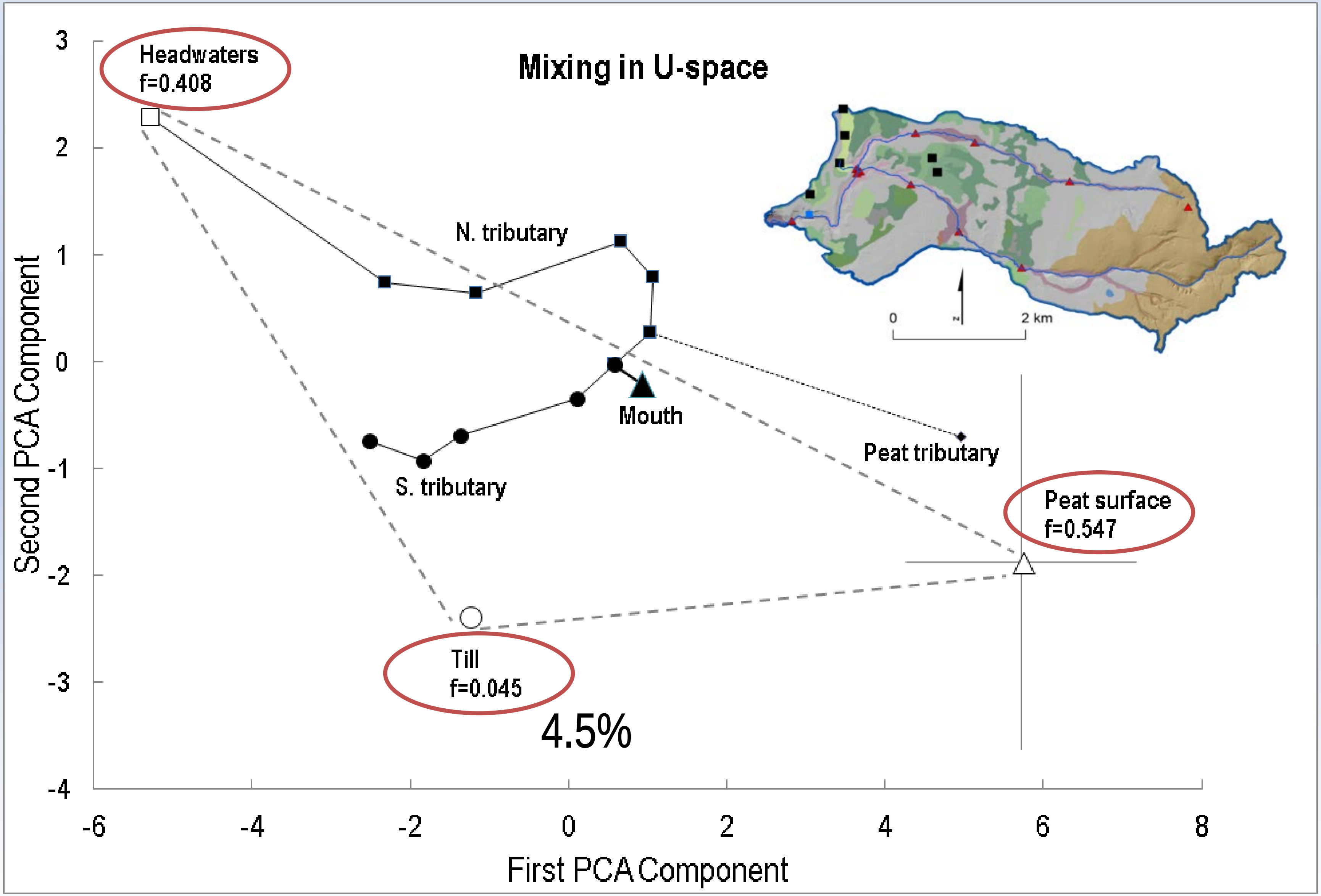


54.7%

3 End-member model



3 End-member model

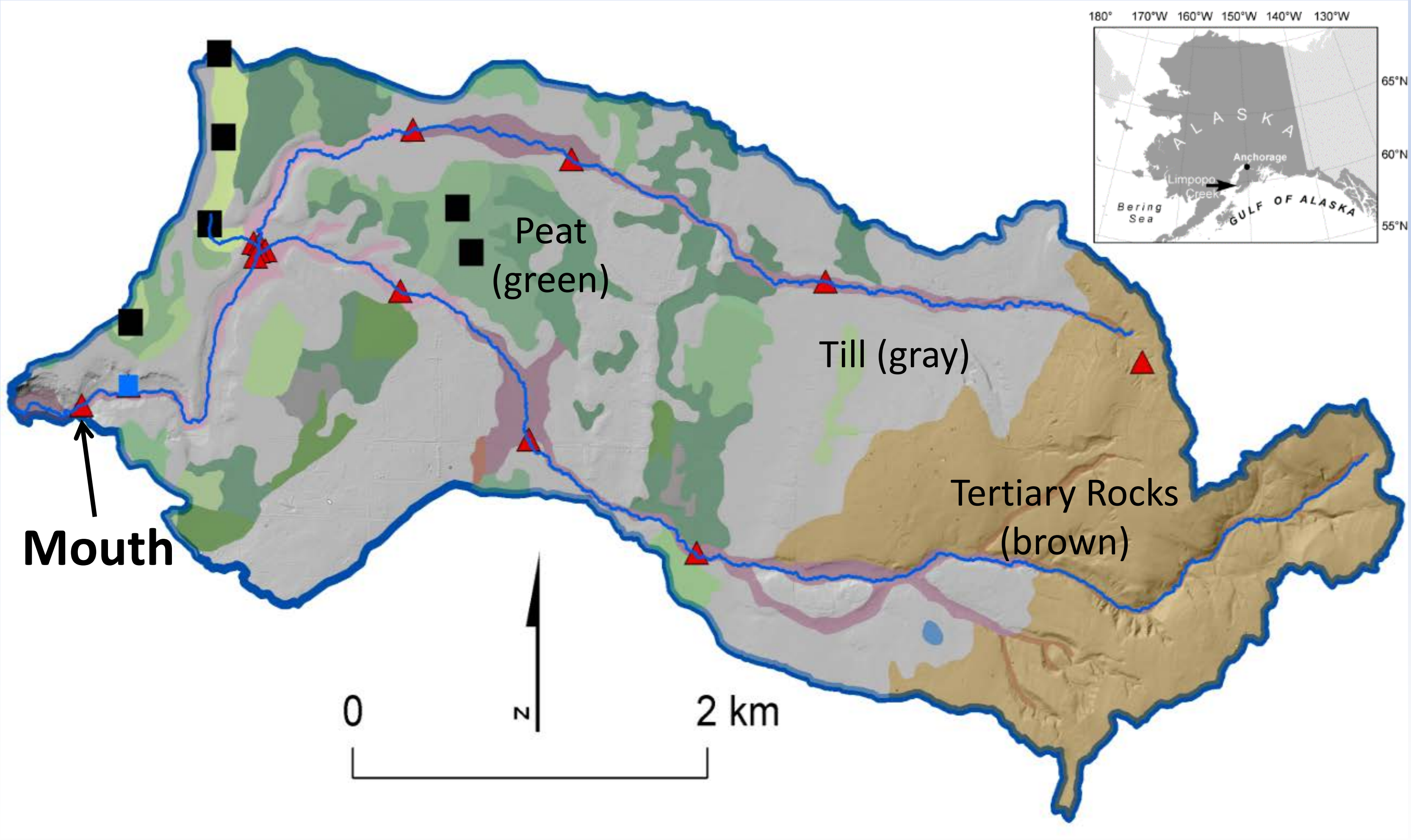


Peat provides 55% of stream flow

= 0.5% of potential contributing volume of watershed

Till = 65%

Tertiary= 35%



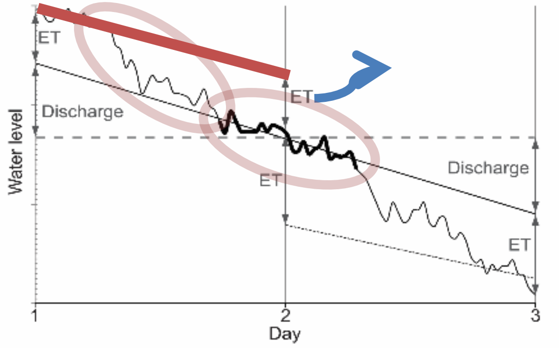
Peat provides 55% of stream flow

Fits reasonable estimates from water budget

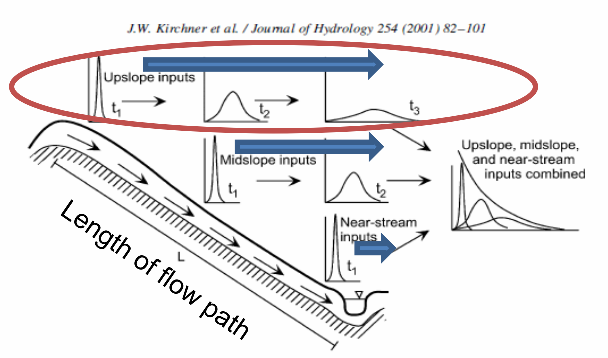
		Specific Yield			
ϕ		**0.45**	**.14**	**0.10**	**0.05**
Thornthwaite	0.8	0.259	0.080	0.060	0.029
	0.9	0.297	0.092	0.066	0.033
	0.131	0	0	0	0
Diurnal ET		0.108	0.033	0.024	0.012

(Actual dry-period flow = 0.06 m^3s^{-1})

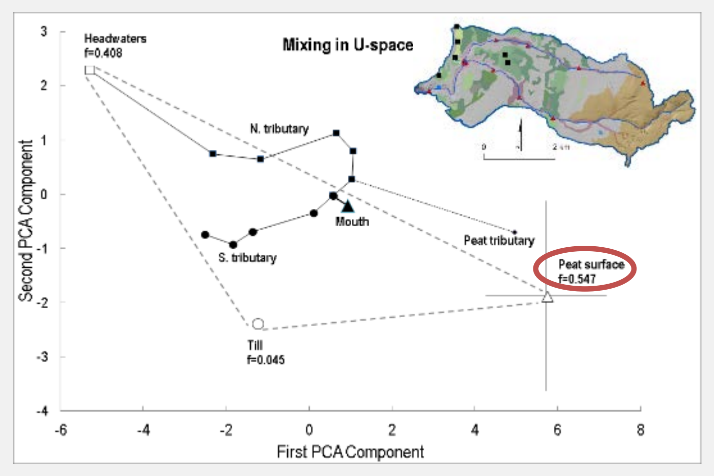
1. **ET estimated using a diurnal method without recharge**



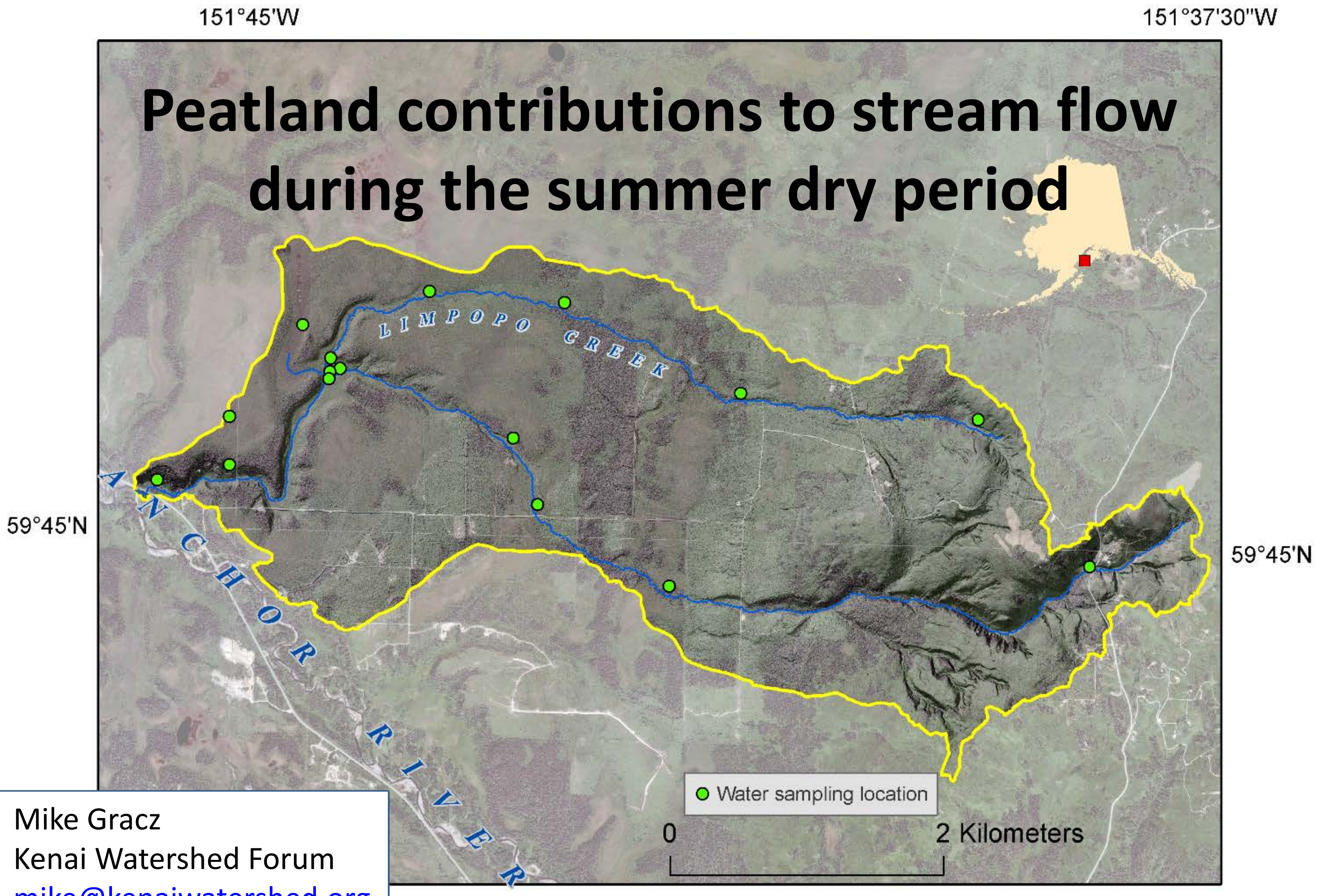
2. **Space-for-Time sampling in EMMA can avoid fractal filtering problems**


J.W. Kirchner et al. / Journal of Hydrology 254 (2001) 82–101

3. **Peat contributes ~55% of dry-season stream flow**



Peatland contributions to stream flow during the summer dry period



Mike Gracz
Kenai Watershed Forum
mike@kenaiwatershed.org
907-235-2218

Gracz, Moffett, Siegel, Glaser 2015. Journal of Hydrology (530)667-676