Predicting the affects of climate change on rivers: a review.

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Outline

- Motivation
- Different methods of river prediction
  - Climate Forcing Model
    - i.e. Hamlet & Lettenmaier, 2001
  - River Characterization Model
    - i.e. Syvitski et al. 2003
- Assumptions for each model
- Strengths and Weaknesses of each model
- Synthesis

Motivation

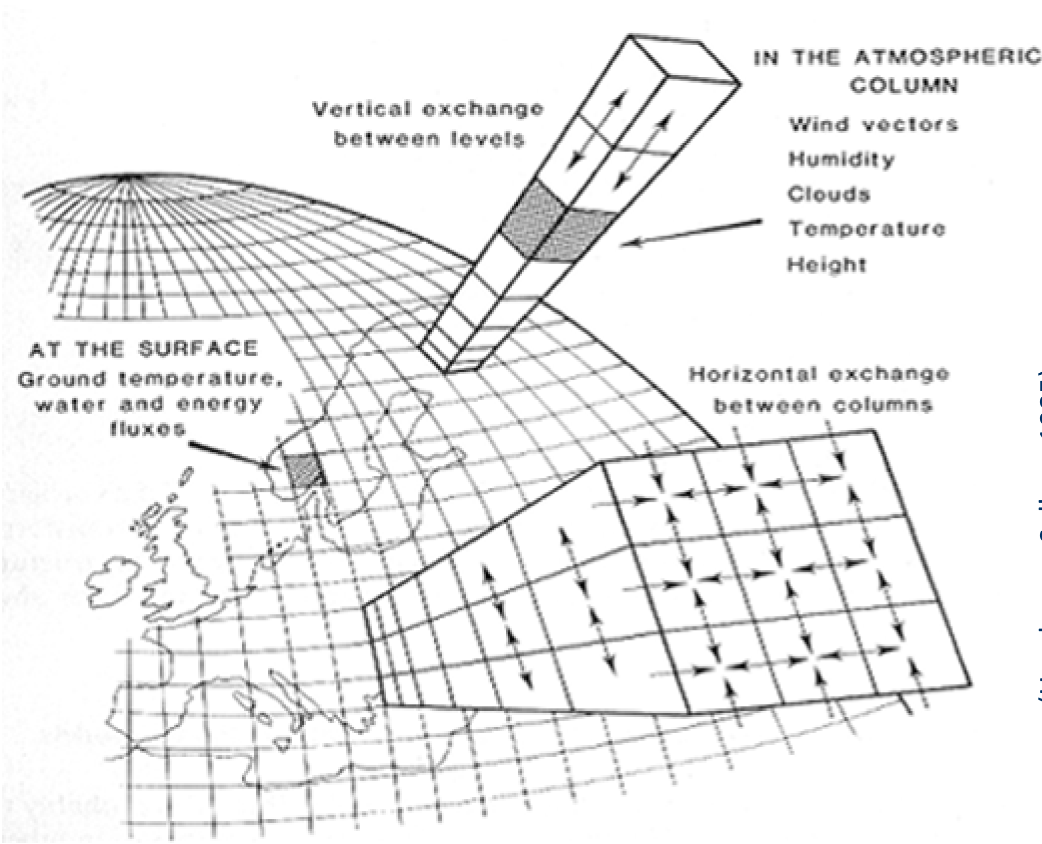

www.wikipedia.org


www.chinadaily.com


www.geo.uu.nl


www.wikipedia.org

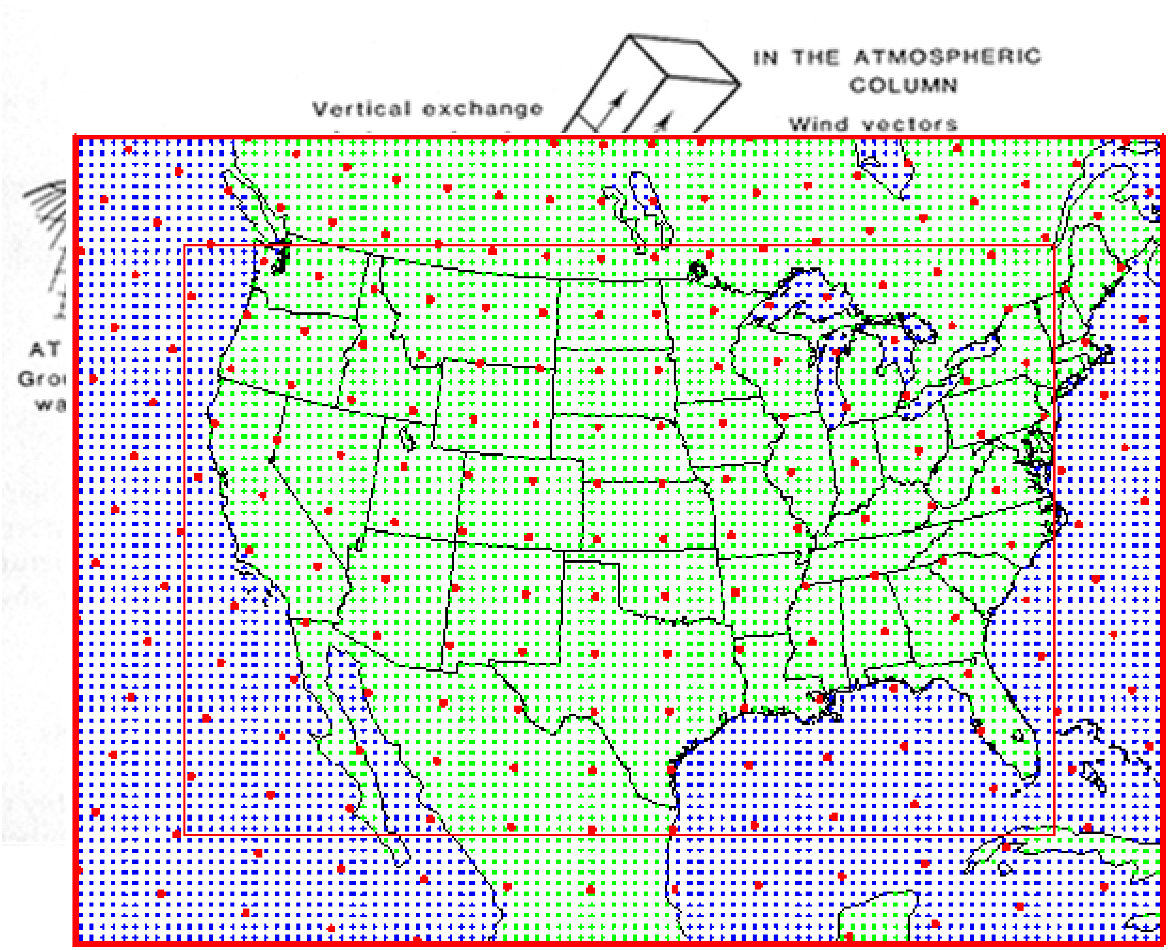
Climate Forcing Model



(Henderson-Sellers, 1985)

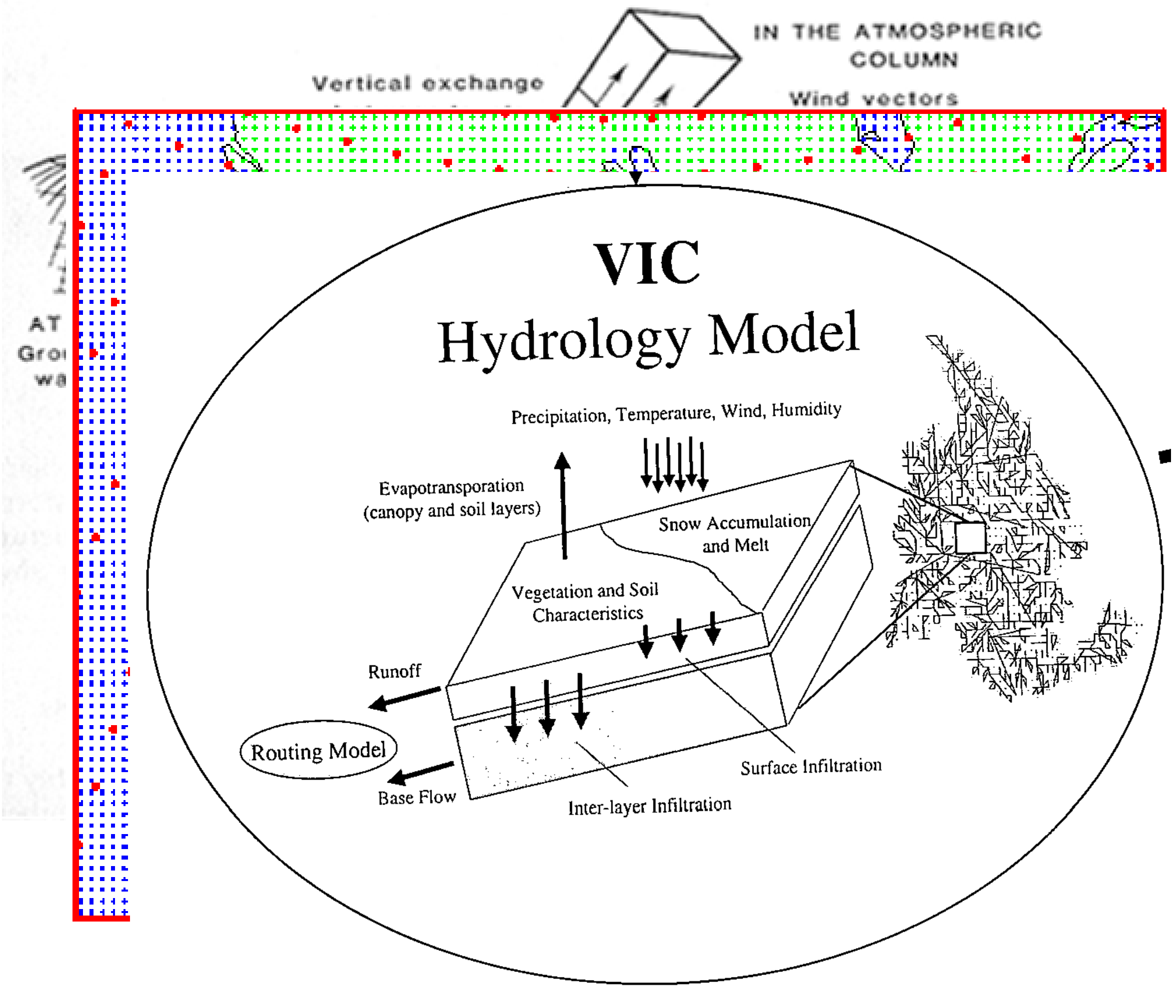
1. **Global Climate Model (GCM)**

Climate Forcing Model



1. Global Climate Model (GCM)
2. **Downscaling/ Nested Regional Climate Model**

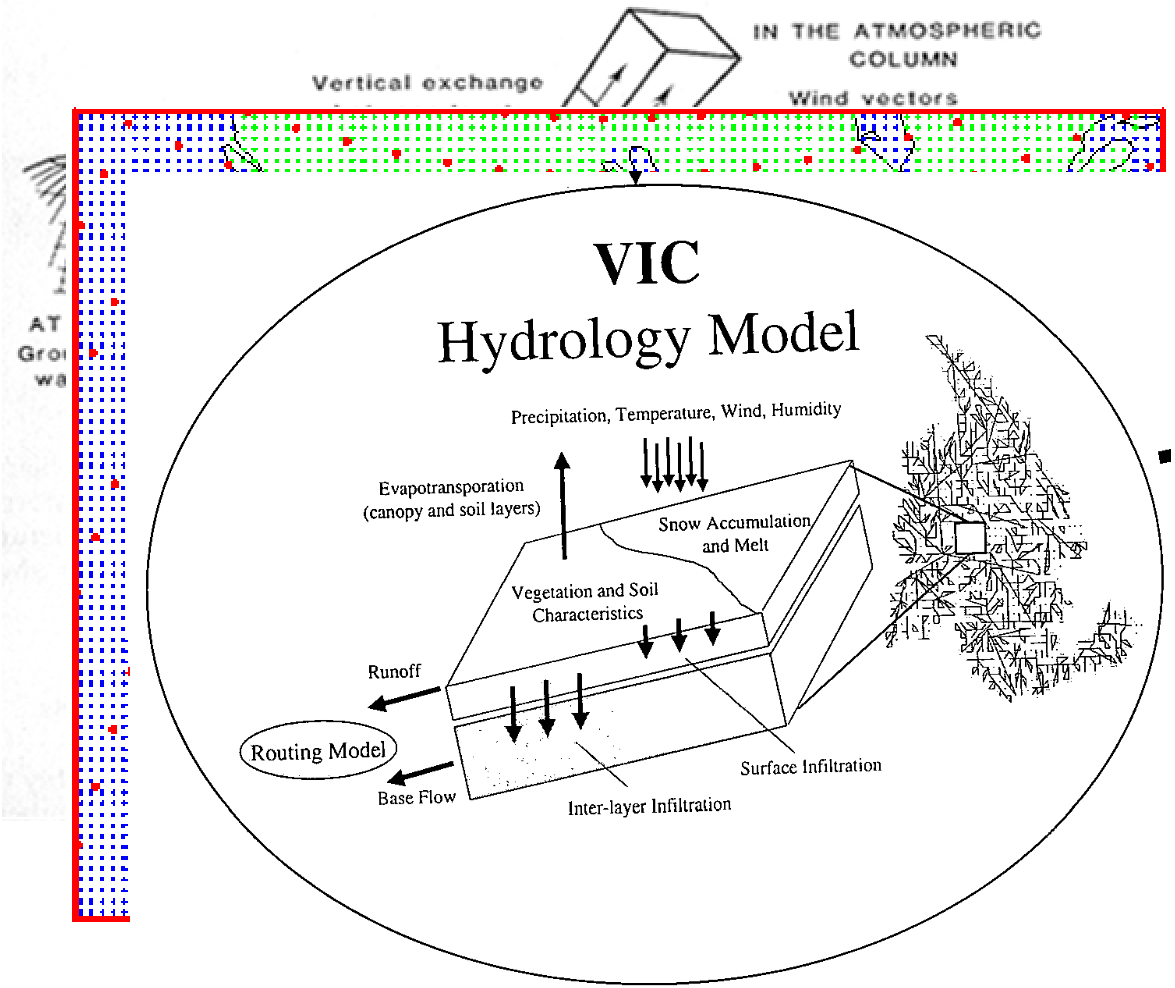
Climate Forcing Model



1. Global Climate Model (GCM)
2. Downscaling/ Nested Regional Climate Model
3. **Variable Infiltration Capacity Model (VIC)**

From Hamlet & Lettenmaier, 1999

Climate Forcing Model



1. Global Climate Model (GCM)
2. Downscaling/ Nested Regional Climate Model
3. Variable Infiltration Capacity Model (VIC)
4. **Flow Routing Model**

From Nijssen et al. 2001

Sample Conclusions

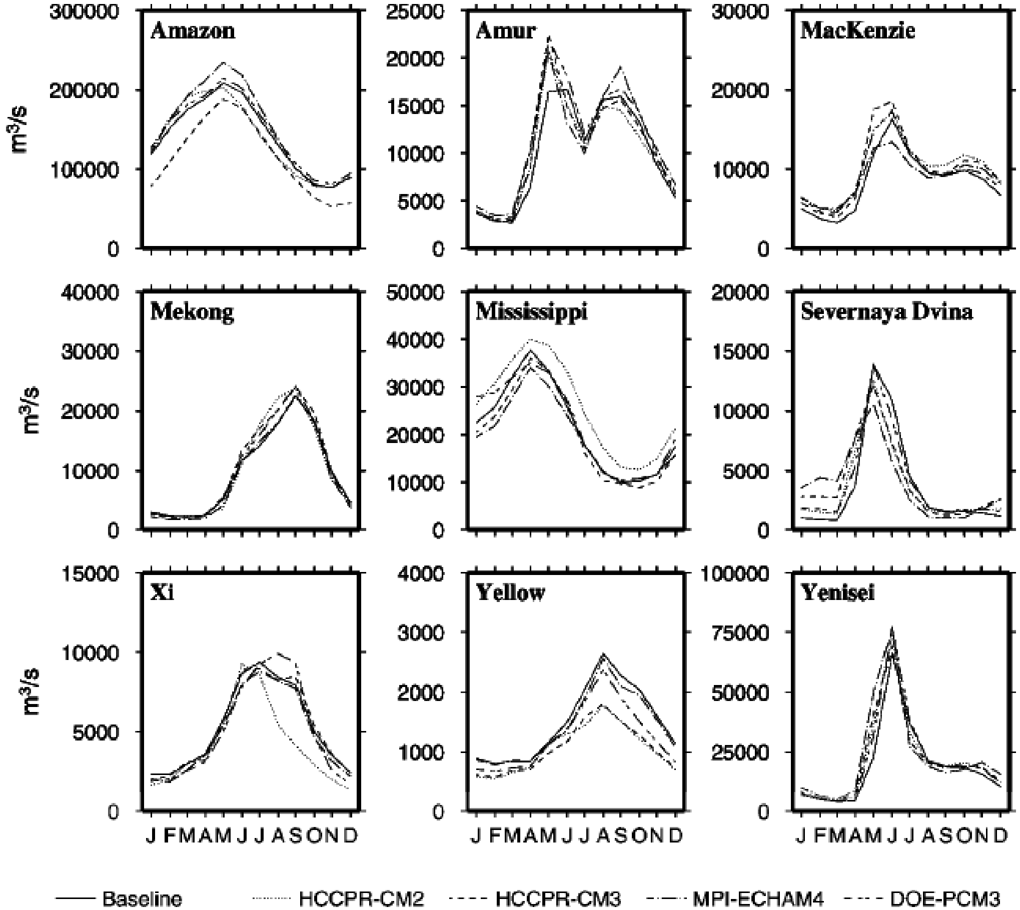


Figure 7. Mean monthly hydrographs for the nine basins for the baseline and climate model simulations in 2040–2049.

For the Columbia River Basin in 2045, based on two Global Climate Models:

- Higher winter streamflow (+50%)
- Reduced March 1 snowpack (-65% to -80%)
- Reduced Spring and Summer streamflow (-10%)

River Characterization Model

Table 1. Drainage properties of 46 Arctic and sub-Arctic rivers derived from the databases of Binda et al (1986), Milliman & Syvitski (1992, with revisions from Bobrovitskaya et al. 1996, 1997), Gordeev (2000) and Syvitski et al. (2000).

River	Receiving ocean	Area[a] (km^2)	H[b] (m)	Mean T[c] (°C)	Q[d] (m^3/s)	Cs[e] (kg/m^3)	Qs[f] (kg/s)	Pred. Qs[g] (kg/s)	T-PQs[h] (kg/s)	Q-PQs[i] (kg/s)	Pred. C[j] (-)	Obs. C[k] (-)	$P\sigma$-c[l] (-)
South (Can)	Atl.	90	1025	-13	1	1.350	2	6	2	1	1.87		0.17
Middle (Can)	Atl.	110	865	-13	2	1.100	2	5	1	1	1.82		0.17
North (Can)	Atl.	190	1060	-13	4	1.160	4	10	3	2	1.93		0.17
Ekalugad Fjord (Can)	Atl.	380	1060	-13	7	1.180	8	13	4	3	1.98		0.17
St. Jean (Can)	Atl.	5600	990	1	1100	0.010	8	47	16	75	2.13		0.19
Murray (Can)	Arct.	5620	1686	-3	452	0.192	87	104	77	174	2.31	2.70	0.18
Homathko (Can)	Pac.	5700	3994	2	253	0.540	136	381	89	527	2.79	2.60	0.17
Odei R (Can)	Atl.	6130	222	0	67	0.075	5	5	5	4	1.67	1.60	0.17
Klinaklini (Can)	Pac.	6500	3800	2	330	0.480	158	378	92	566	2.77		0.18
N Saskatchewan (Can)	Atl.	11000	2212	-4	156	0.891	139	218	146	128	2.49	2.40	0.17
Romaine (Can)	Atl.	14000	650	0			5	39	17		2.03		
Arctic Red (Can)	Arct.	18600	2452	-4	752	0.192	452	331	222	237	2.60	2.80	0.18
Stikine (Can)	Pac.	18800	1808	4	578	0.296	171	211	82	253	2.42	2.60	0.18
Muskwa (Can)	Arct.	20300	2522	0	452	1.520	687	361	92	364	2.59	2.40	0.18
Abitibi (Can)	Atl.	24000	430	-3	1680	0.003	4	28	20	46	1.95		0.20
Kymijoki (Fin)	Atl.	37240	80	3	288	0.020	5	3	3	2	1.56		0.18
Skeena (Can)	Pac.	42000	2409	4	918	0.380	349	485	174	574	2.62	2.70	0.19
Colville (US)	Arct.	50000	4800	-17	492	0.390	190	1487	269		3.14		0.18
Attawapiskat (Can)	Atl.	50200	430	-1	626	0.010	6	40	35	21	2.02		0.18
Onega (Rus)	Arct.	57000	147	-4	500	0.018	10	9	6	4	1.75		0.18
Moose (Can)	Atl.	60000	400	0	780	0.020	13	39	22	27	2.00		0.18
Nadym (Rus)	Arct.	64000	550	-9	570	0.022	13	11	26	2	1.83		0.18
Nottaway (Can)	Atl.	65800	400	3	1130	0.030	32	41	27	38	2.00		0.19
Alazeya (Rus)	Arct.	68000	914	-14	280	0.080	22	144	36	12	2.32		0.18
Peel (Can)	Arct.	70600	2362	-4	1492	0.896	1337	610	409	327	2.68	2.60	0.20
Mezen (Rus)	Arct.	78000	900	-10	860	0.032	29	57	56	21	2.09		0.19
Kuskokwim (US)	Pac.	80500	3700	-7	1293	0.200	254	1277	634	398	2.98		0.19
Anabar (Rus)	Arct.	100000	536	-14	550	0.024	13	78	19	8	2.18		0.18
Pyr (Rus)	Arct.	112000	168	-9	1080	0.018	19	15	6	3	1.87		0.19
Taz (Rus)	Arct.	150000	312	-9	1400	0.021	29	43	17	10	2.09		0.20
Pyasina (Rus)	Arct.	182000	1100	-14	2730	0.040	108	311	75	65	2.45		0.22
Olenjok (Rus)	Arct.	219000	962	-14	1140	0.031	35	279	71	29	2.42		0.19
Yana (Rus)	Arct.	220000	2369	-19	906	0.100	95	1082	162	51	2.83		0.19
Pechora (Rus)	Arct.	250000	1103	-6	3367	0.060	193	366	201	187	2.43		0.23
Liard (Can)	Arct.	275000	2742	-2	4302	0.600	2580	1506	1233	837	2.85	2.80	0.25
Peace (Can)	Arct.	293000	3702	1	2597	0.987	2563	2438	659	2526	3.01	2.60	0.22
Indigirka (Rus)	Arct.	305000	2682	-14	1711	0.260	444	1533	394	147	2.90		0.20
N. Dvina (Rus)	Arct.	357000	500	-6	3470	0.035	120	50	73	22	2.03		0.23
Kolyma (Rus)	Arct.	361000	1828	-11	2839	0.070	380	939	303	125	2.71		0.22
Khatanga (Rus)	Arct.	364000	2036	-14	2700	0.020	54	1109	265	143	2.76		0.22
Yukon (US)	Pac.	828800	6094	-12	6122	0.310	1901	8872	2609	1977	3.60		0.28
MacKenzie (Can)	Arct.	1660000	3877	-5	10915	0.366	2219	6218	3661	2683	3.20	3.00	0.37
Amur (Rus)	Pac.	1850000	2133	-1	10552	0.160	1648	2680	2524	1228	2.84		0.36
Yenisei (Rus)	Arct.	2440000	3352	-13	17986	0.020	412	6062	1652	979	3.17		0.50
Lena (Rus)	Arct.	2486000	2529	-14	16650	0.034	558	4011	989	538	3.01		0.47
Ob (Rus)	Arct.	2929290	3657	-12	10299	0.050	507	7570	2280	938	3.24		0.36

[a] Area is drainage area at gauging station.
[b] H is relief between highest elevation and gauging station.
[c] Mean T is basin temperature averaged over drainage basin.
[d] Q is discharge.
[e] Cs is discharge-weighted sediment concentration.
[f] Qs is sediment load.
[g] Predicted Qs is from $Qs = \beta H^3/2A^{1/2}$.
[h] T-PQs is the basin T-corrected Qs predicted from Eq. (6).
[i] Q-PQs is the Qs predicted from Eq. (7) using basin discharge.
[j] Pred. C is the rating coefficient predicted from Eq. (4).
[k] C is the measured rating coefficient.
[l] $P\sigma$-c is the predicted standard deviation of C.

1. Collect a large river database

From Syvitski, 2002

River Characterization Model

Table 1. Drainage properties of 46 Arctic and sub-Arctic rivers derived from the databases of Binda et al (1986), Milliman & Syvitski (1992, with revisions from Bobrovitskaya et al. 1996, 1997), Gordeev (2000) and Syvitski et al. (2000).

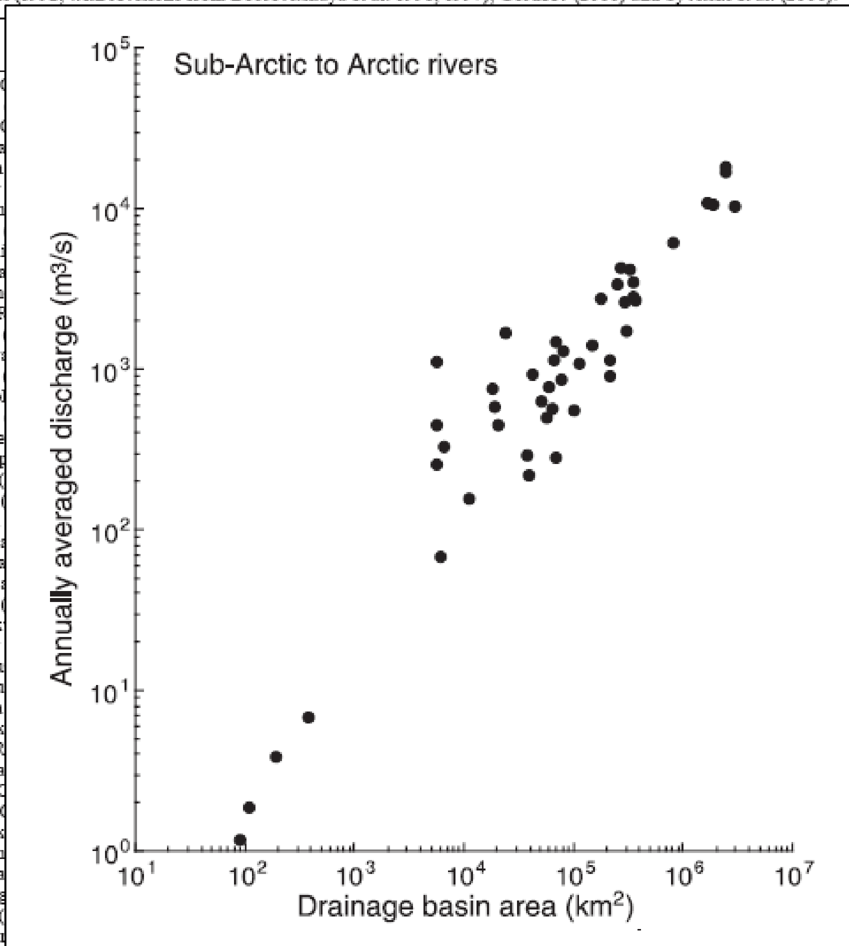


Fig. 2. The annually averaged discharge (Q) scales with the drainage basin area (A) for sub-Arctic and Arctic rivers ($Q = 0.93A^{0.82}$ at $R^2 = 0.892$; Table 1).

1. Collect a large river database
2. **Data Analysis**

From Syvitski, 2002

River Characterization Model

Table 1. Drainage properties of 46 Arctic and sub-Arctic rivers derived from the databases of Binda et al (1986), Milliman & ... 2000) and Syvitski et al. (2000).

Pred. Qs[g] (kg/s)	T-PQs[h] (kg/s)	Q-PQs[i] (kg/s)	Pred. C[j] (-)	Obs. C[k] (-)	$P\sigma$-c[l] (-)

Table 6
Regression coefficients on $Qs = \alpha_6 Q^{\alpha_7} R^{\alpha_8} e^{kT}$

Global sector	No. of rivers	α_6	α_7	α_8	k	R^2
Polar ($T < 0$ °C)*	34	1.3×10^{-4}	0.55	1.5	0.1	0.78
Temperate N (lat.>30°N, $T > 0$ °C)	128	1.1×10^{-3}	0.53	1.1	0.06	0.49
Tropics N (lat. 0–30°N)	53	2.0	0.45	0.57	– 0.09	0.54
Tropics S (lat. 0–30°S)	36	162	0.65	– 0.05	– 0.16	0.76
Temperate S (lat.>30°S, $T > 0$ °C)	16	?	?	?	?	?

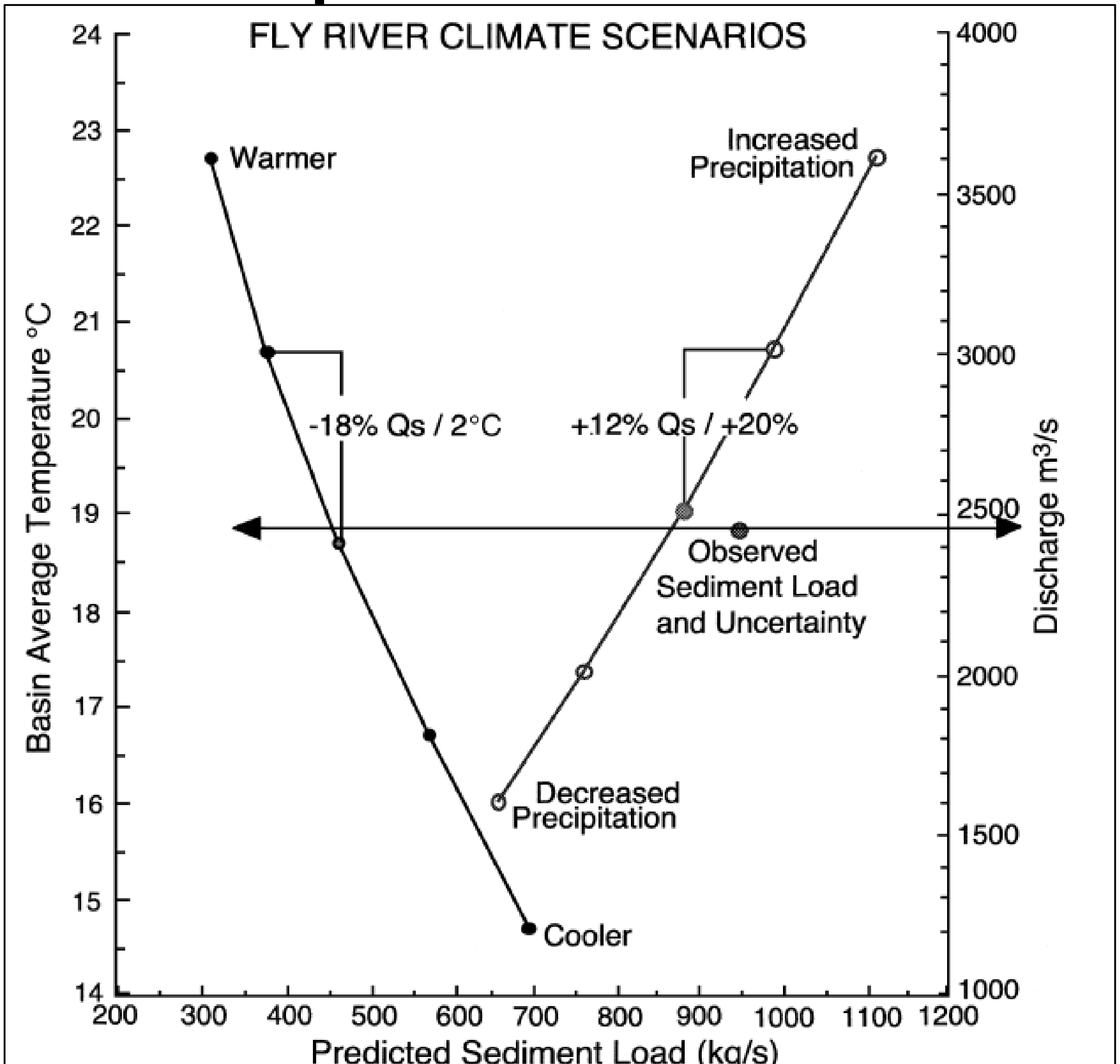
T is basin-average temperature (°C), H is maximum relief from sea level to the mountain top (m), Qs is long term sediment load (kg/s), Q is average discharge (m^3/s).

[c]Mean T is basin temperature averaged over drainage basin.
[d]Q is discharge.
[e]Cs is discharge-weighted sediment concentration.
[f]Qs is sediment load.
[i]Q-PQs is the Qs predicted from Eq. (7) using basin discharge.
[j]Pred. C is the rating coefficient predicted from Eq. (4).
[k]C is the measured rating coefficient.
[l]$P\sigma$-c is the predicted standard deviation of C.

1. Collect a large river database
2. Data Analysis
3. **Define Predictive Relationships**

From Syvitski, 2002

Sample Conclusions



"model predicts sediment discharge within a factor of 2 for 75% of Earth's rivers across 5 orders of magnitude in Basin Area and Discharge"

Assumptions

Climate Forcing Model

- Models work
- Downscaling works

River Characterization Model

- All rivers are subject to the same forces
- All rivers are in equilibrium
- Rivers have been sampled without bias
- River data is accurate

Strengths

Climate Forcing Model

- Can test many different climate scenarios quickly
- Can predict timescales of change

River Characterization Model

- Can be used over a wide range of scales
- Relationship is easier to understand

Weaknesses

Climate Forcing Model

- Hard to identify the agents of change with so many models
- Only can be used for large scale rivers
- Downscaling problematic

River Characterization Model

- Correlation does not imply causation
- Equilibrium conditions?
- No information about dynamics of change

Synthesis

- Both methods are well founded
- They work well in different places
- Great benchmark for one another

References

Hamlet A.F., Lettenmaier, D.P.: 1999 ‘Effects of Climate Change on Hydrology and Water Resources of the Columbia River Basin’, *J. Amer. Water Resour. Assoc.* **35**, 1597-1623.

Nijssen, B., O’Donnell, G.M., Hamlet, A.F., and Lettenmaier, D.P.: 2001 ‘Hydrologic Sensitivity of Global Rivers to Climate Change’, *Climatic Change*. **50**, 143-175.

Syvitski, J.P.M.: 2002 ‘Sediment Discharge Variability in Arctic Rivers’, *Polar Research*. **21**, 323-330.

Syvitski, J.P.M., Peckham, S.D., Hilberman, R., Mulder, T.: 2003 ‘Predicting the terrestrial flux of sediment to the global ocean: a planetary perspective’, *Science*. **162**, 5-24.