TABLE 1. RIVER BASIN AREAS DRAINING TO LAKE WINNIPEG SUBBASINS

River basin	Receiving basin	Period	Area (km^2)	Source and comment
Saskatchewan River	North Basin	4.7 to 0 ka	335 900	National Atlas of Canada (NAC), 1985
Manitoba-Winnipegosis	North Basin	7.7 to 0 ka	80 300	Last and Teller, 1983*; includes estimated (this study) lake areas of 10 500 km^2
North Basin local[†]	North Basin	7.7 to 0 ka	82 730	this study; estimated from NAC, 1985, 1: 7 500 000 scale map
Central Basin local[§]	North Basin	7.7 to 0 ka	26 230	this study; estimated from NAC, 1985, 1: 7 500 000 scale map
Assiniboine River	North Basin South Basin	7.5 to ca./< 4 ka >7.5 & ca./< 4 ka	180 200	NAC, 1985; modified by including lower 1800 km^2 in Red River basin
Red River	South Basin	~8 to 0 ka	107 300	NAC, 1985; see note above
Winnipeg River	South Basin	~8 to 0 ka	135 800	NAC, 1985
South Basin local [#]	Central/North Basin	~8 to 0 ka	10 670	this study; estimated from NAC, 1985, 1: 7 500 000 scale map
Sum			959 130	2.4 % less than the total catchment (982 900 km^2) in NAC, 1985.

*From Last, W.M., and Teller, J.T., 1983, Holocene climate and hydrology of the Lake Manitoba basin, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz: St. John's, Newfoundland, Geological Association of Canada Special Paper 26, p. 333-353.

[†]Between Pigeon and Warren Landing sills; includes land and lake areas.

[§]Between Hecla-Black and Pigeon sills; includes land and lake areas.

[#]South of Hecla-Black Sill; includes land and lake areas.

TABLE 2. CLIMATE-SUSTAINABLE LAKE AREAS AND POTENTIAL OPEN-LAKE AREAS FOR SOUTHERN BASIN OF LAKE WINNIPEG

Age (cal. yr B.P./ ka)	South Basin drainage area*	Climate-sustainable lake area A (km^2)†			Potential open-lake area (km^2)#
		Grassland Border	Central Grassland	Central Grassland sr §	
8 260/ 7.5	+AR	19 431	2 695	677	500
8 260/ 7.5	-AR	11 363	1576	396	500
7 560/ 6.7	-AR	11 363	1576	396	610
6 680/ 5.9	-AR	11 363	1576	396	860
5 510/ 4.8	-AR	11 363	1576	396	1280
4 440/ 4.0	-AR	11 363	1576	396	1475
4 440/ 4.0	+AR	19 431	2 695	677	1475
3 750/ 3.5	+AR	19 431	2 695	677	1600
3 060/ 2.0	+AR	19 431	2 695	677	2730

*433 970 km^2 with Assiniboine River drainage = +AR; 253 770 km^2 without Assiniboine River drainage = -AR.

†Calculated using $A = A_b q/(q + e_p - p)$.

§sr = supressed runoff.

#Calculated by open-lake tilting model. Ground uplift since t years ago at a site relative to Isobase 5 (Teller and Thorleifson, 1983) was computed from a(exp(t/*)-1) (equation 1) (Todd et al., 2000; Tackman et al., 1998; Peltier, W.R., 1994, Ice age paleotopography: Science, v. 265, p. 195-201). The site-specific amplitude parameter $a = RU_B$/(exp(9500/*)-1) where RU_B = height of the Burnside level of Lake Agassiz at the site above its elevation at Isobase 5 south of Lake Winnipeg, and the age of the Burnside level = 9500 cal. yr B.P. The relaxation parameter *, assumed to be a constant throughout the Lake Winnipeg basin, was evaluated at 3 500 years in the Lake Winnipegosis area where the gradients and ages of several postglacial shorelines including the Burnside level are known (Tackman et al., 1998); * was found by solving simultaneous equations in the form of equation 1, where the parameters, $a = RU_B$, a constant for the site, and t were evaluated or substituted by the known gradient and age of each paleoshoreline around Lake Winnipegosis. At age t, the elevation E_t of a site $= E_p - Ru_t$ (equation 2) where E_p is the present site elevation, and RU_t is the site uplift since t cal. yr B.P. By using equation 2, the past elevation was computed at points in southern, central, and northern Lake Winnipeg to determine the slope or tilt of a former level lake surface achieved for 7 phases since 7.9 ka (8 840 cal. yr B.P.). Using a geographic information system and a digital elevation and bathymetry model of the Lake Winnipeg basin constructed with an allowance for ongoing sediment accumulation, the intersections and enclosed areas of the 7 tilted planes with the basin topography and bathymetry model at sill elevations were obtained to represent potential lake shorelines (Fig. 2) and areas of water surfaces overflowing their sills in subbasins and basins of Lake Winnipeg.

TABLE 3. RADIOCARBON AGE DETERMINATIONS BY ACCELERATOR MASS SPECTROMETRY OF FOSSILS IN BASAL LAKE WINNIPEG SEDIMENTS (LWS)

Site	Latitude*	Longitude*	LWS* base (cm)	Level of date* (cm)	Fossil material dated*	Lab number*	Conventional age (^{14}C yrs B.P.)*	Calibrated age (cal. yrs B.P.) and 1- sigma age range[†]
104	53^{o} 35.1'N	98^{o} 05.1'W	>243	237-243	twigs of wood[§]	CAMS-32 189	7 700 Å 50	(8 440) 8 530-8 410
106	53^{o} 34.7'N	98^{o} 05.8'W	182	176-182	*Candona rawsoni* (Tressler) and *C. subtriangulata* (Benson and MacDonald) ostracodes	CAMS-32 191	6 560 Å 200[#]	(7 560) 7 680-7 410
122	50^{o} 39.4'N	96^{o} 48.3'W	435	425-433	*Scirpus* sp. seed	CAMS-17 434	4 040 Å 70	(4 520) 4 590-4 420
201	53^{o} 12.0'N	99^{o} 06.9'W	439	434-439	*Picea* needles	CAMS-35 499	4 800 Å 70	(5 580) 5 600-5 470
202	53^{o} 43.2'N	98^{o} 36.2'W	179	174-179	ostracodes as at site 106	CAMS-32 192	6 460 Å 60[#]	(7 410) 7 430-7 310
204	53^{o} 34.0'N	98^{o} 06.3'W	>579	362-373	ostracodes as at site 106	CAMS-38 676	6 350 Å 80[#]	(7 410) 7 440-7 290
204	53^{o} 34.0'N	98^{o} 06.3'W	>579	513-518	*Picea* sp. needle	CAMS-38 678	6 750 Å 70	(7 600) 7 670-7 570
209	52^{o} 30.9'N	97^{o} 34.8'W	104	95-97	*Juniperus communis* L. seed	CAMS-35 497	3 730 Å 70	(4 080) 4 170-3 970
213	51^{o} 52.4'N	96^{o} 56.5'W	15	10-15	*Picea* needle	CAMS-46 187	2 540 Å 60	(2 720) 2 750-2 500
215	51^{o} 22.5'N	96^{o} 34.3'W	361	321.5	*Scirpus* sp. seed	CAMS-34 554	3 950 Å 60	(4 410) 4 500-4 310
215	51^{o} 22.5'N	96^{o} 34.3'W	361	348	*Scirpus* sp. seed	CAMS-34 555	4 030 Å 50	(4 510) 4 550-4 430
217	51^{o} 08.0'N	96^{o} 35.1'W	302	253-257	*Chenopodium* sp. seeds	CAMS-46 191	3 910 Å 60	(4 400) 4 420-4 250
221	50^{o} 56.1'N	96^{o} 37.0'W	522	523-528	*Scirpus* sp. seed**	CAMS-38 680	4 190 Å 100	(4 820) 4 850-4 550
221	50^{o} 56.1'N	96^{o} 37.0'W	522	526-527	*Sphaerium striatinum* (Lamarck) shell**	CAMS-35 616	3 970 Å 50 [#]	(4 540) 4 590-4 440
222	50^{o} 56.1'N	96^{o} 44.2'W	735	735-740	*Scirpus* sp. seed**	CAMS-46 188	4 710 Å 50	(5 460) 5 570-5 320
223	50^{o} 39.4'N	96^{o} 48.3'W	687	661-666	*Scirpus* sp. seed	CAMS-34 551	4 000 Å 60	(4 430) 4 530-4 410
223	50^{o} 39.4'N	96^{o} 48.3'W	687	721-726	*Scirpus* sp. seed**	CAMS-46 186	4 030 Å 50	(4 510) 4 550-4 430
224	50^{o} 33.0'N	96^{o} 47.2'W	>731	577-582	*Helianthus* sp. seed	CAMS-35 496	3 550 Å 70	(3 850) 3 910-3 710

TABLE 3 continued. RADIOCARBON AGE DETERMINATIONS BY ACCELERATOR MASS SPECTROMETRY OF FOSSILS IN BASAL LAKE WINNIPEG SEDIMENTS (LWS)

Site	Latitude*	Longitude*	LWS* base (cm)	Level of date* (cm)	Fossil material dated*	Lab number*	Conventional age (^{14}C yrs B.P.)*	Calibrated age (cal. yrs B.P.) and 1 sigma age range[†]
224	50° 33.0'N	96° 47.2'W	>731	577-582	*Scirpus* sp. seeds	CAMS-35 501	3 570 Å 120	(3 850) 4 070-3 700
224	50° 33.0'N	96° 47.2'W	>731	584-589	*Scirpus* sp. seed[§]	CAMS-46 192	5 350 Å 50	(6 180) 6 200-6 010
224	50° 33.0'N	96° 47.2'W	>731	705-710	*Musculium lacustre* (Müller) and *Sphaerium rhomboideum* (Say) shells	CAMS-35 615	3 740 Å 60[#]	(4 240) 4 370-4 160
215	51° 22.5'N	96° 34.3'W	361	348	*M. transversum* (Say) *and* M. *lacustre (*Müller) shells	CAMS-71 709	4 590 Å 40	hwe (difference)[#] = 560 yrs
215	51° 22.5'N	96° 34.3'W	361	348	*Scirpus* sp. seed	CAMS-34 555	4 030 Å 50	
221	50° 56.1'N	96° 37.0'W	522	523-528	*M. lacustre (*Müller) shell**	CAMS-71 710	4 420 Å 40	hwe (difference)[#] = 230 yrs
221	50° 56.1'N	96° 37.0'W	522	523-528	*Scirpus* sp. seed**	CAMS-38 680	4 190 Å 100	
223	50° 39.4'N	96° 48.3'W	687	507-509	*M. transversum* (Say) and *M. lacustre (*Müller) shells	CAMS-71 708	3 620 Å 40	hwe (difference)[#] = 340 yrs
223	50° 39.4'N	96° 48.3'W	687	507-509	*Scirpus* sp. seed	CAMS-34 550	3 280 Å 60	
	51° 40'N	96° 35'W	from Winnipeg River mouth		live *Strophitus undulatus* (Say) shell, A.D. 1941	GSC-3281	440 Å 100	hwe = 280 yrs[#]

*From Todd et al., 1996, 2000.

[†]Calibrated with the program CALIB4.3 by using 1998 atmospheric decadal data set (Stuiver et al., 1998) and 50-year moving average.

[F§]fossils show abrasion, indicating transportation, all others are assumed to have been deposited close to their source.

[#]Corrected for hard-water effect (hwe) by subtracting 350 years, average of 4 hwe determinations in last 7 rows of this table. Last (modern) shell age (Nielsen, E., McKillop, W.B., and McCoy, J.P., 1982, The age of the Hartman moraine and the Campbell beach of Lake Agassiz in northwestern Ontario: Canadian Journal of Earth Sciences, v. 19, p. 1933-1937) corrected for fossil fuel effect following Rea, D.K., and Colman, S.M., 1995, Radiocarbon ages of pre-bomb clams and the hard-water effect in Lakes Michigan and Huron: Journal of Paleolimnology, v. 14, p. 89-91, and Moore, T.C., Jr., Rea, D.K., and Godsey, H.S., 1998, Regional variation in radiocarbon ages and the hard-water effects in Lakes Michigan and Huron: Journal of Paleolimnology, v. 20, p. 347-351.

**fossil introduced below Lake Winnipeg sediment possibly by bioturbation (221, 222), or ice scour (223).

TABLE 4. AGE DETERMINATIONS OF CORE 103 SEDIMENTS BY CORRELATION OF PALEOMAGNETIC INCLINATION FEATURES TO SIMILAR FEATURES IN OTHER RADIOCARBON-DATED LAKE SEDIMENTS*

Core depth (cm)*	Inclination feature*	Conventional 14C age (ka B.P.)*	Calibrated age (cal. yrs B.P.) and 1 sigma age range[†]	Core depth range *D* (m)	Equations for model age[§] *AG* (ka B.P.) at core depth *D* (m)
0		0	0	0-2.01	$AG = 0.00071 + 1.76754D - 0.35954D^2$ Data points = 6; R^2 (degree 1) = 0.943 R^2 (degree 2) = 0.999
58	1	0.915 Å 130	(810) 950-690		
94	2	1.325 Å 140	(1270) 1340-1080		
112	3	1.523 Å 90	(1400) 1520-1320		
130	4	1.71 Å 120	(1610) 1740-1510		
200	5	2.095 Å 170	(2060) 2330-1880	1.99-4.99	$AG = -2.4986 + 2.7957D - 0.24562D^2$ Data points = 6; R^2 (degree 1) = 0.957 R^2 (degree 2) = 0.998
225	6	2.515 Å 140	(2720) 2770-2360		
270	7	3.338 Å 330	(3570) 3980-3220		
319	8	3.948 Å 260	(4410) 4830-3990		
375	9	4.456 Å 190	(5050) 5430-4840		
498	9.5	5.35 Å 200	(6180) 6310-5910	4.97-5.21	$AG = -19.6179 + 5.0136D$ Data = 2; $R^2 = 1$
520	10	6.453 Å 260	(7410) 7590-7030	5.19-6.86	$AG = 0.98598 + 1.6295D - 0.11119D^2$ Data points = 3; R^2 (degree 1) = 0.968 R^2 (degree 2) = 1
604	11	6.772 Å 160	(7610) 7740-7490		
685	12	6.931 Å 170	(7740) 7940-7600		

*From Todd et al., 2000.
[†]Calibrated with the program CALIB4.3 by using 1998 atmospheric decadal data set (Stuiver et al., 1998) and 50-year moving average.
[§]Model curve fitted with the program GRAPHER; R^2 = coefficient of determination.

TABLE 5. HYDROLOGICAL PARAMETERS FOR CLIMATES AND CLIMATE-SUSTAINABLE LAKE AREAS

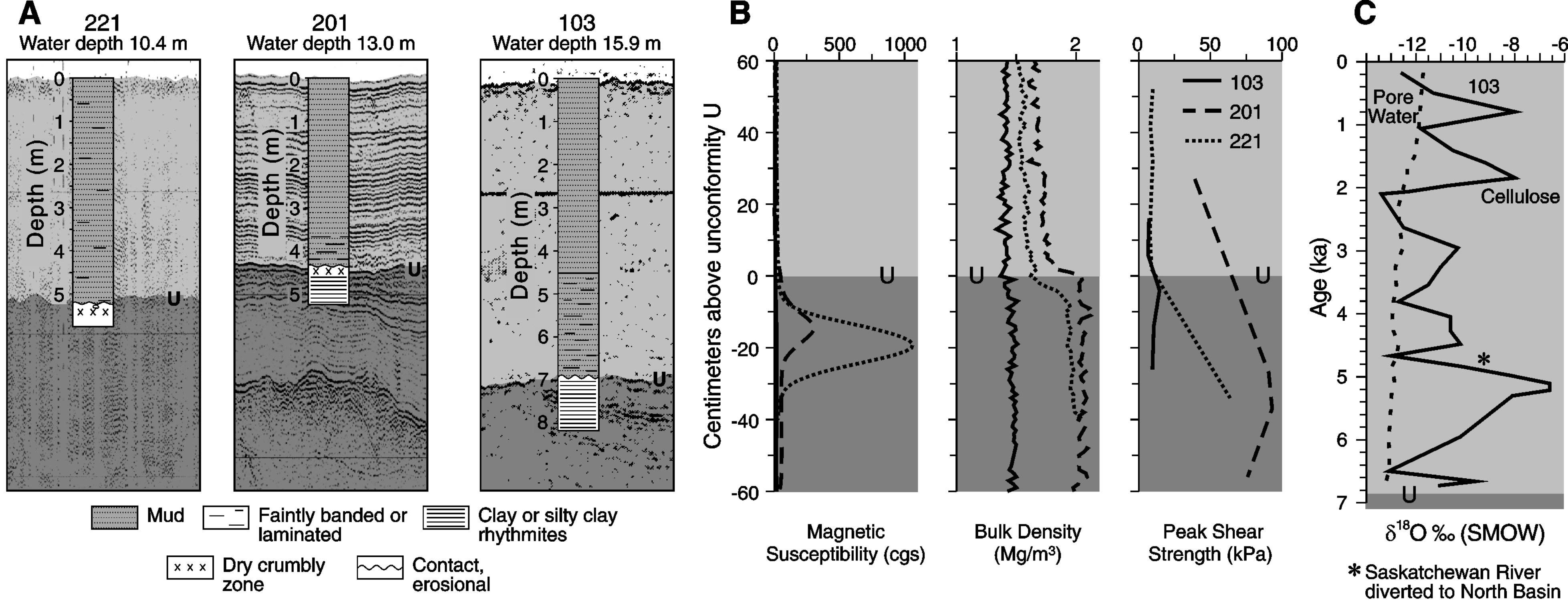
Climate	q runoff (mm/y)r*	e_p potential evaporation (mm/yr)†	p precipitation (mm/yr)	Source or comment	$p - e_p$ (mm/yr)	Change in $p - e_p$ from modern climate (mm/yr)	Lake area A (km^2)§
Modern	145	700	550	Average of parameter ranges in Lake Winnipeg watershed from CNCIHD,1978, hereafter HAC, 1978	-150	0	483 120
Grassland Border	15	700	380	Selected from HAC, 1978 for the boundary zone between grassland and forest vegetation near Saskatoon, Saskatchewan	-320	-170	44 010
Central Grassland	4	940	300	Selected from HAC, 1978 for the drier area of grassland near Medicine Hat, Alberta	-640	-490	6 100
Central Grassland (suppressed runoff)	1	940	300	A drier version of the central-grassland climate representing the effective climate in the desiccated middle Holocene southern basin of Lake Winnipeg	-640	-490	1 530

*Runoff is given per unit area of the land portion of the drainage basin.

†Evaporation is lake or potential evaporation.

§Lake area, A, is the maximum steady-state climate-sustainable lake area for the present Lake Winnipeg basin (982 900 km^2). Compare with the present area of Lake Winnipeg (24 400 km^2) or with the combined lake area of 34 900 km^2 for the large lakes Winnipeg, Manitoba and Winnipegosis in the Lake Winnipeg basin (Fig. 1). Lake Winnipeg would not be supported as an open, overflowing lake by the Central Grassland climate.

Figure R1. Lake Winnipeg sediment properties at sites in the southern basin (221), and northern basin (201 and 103). (A) Sediment lithology recovered by piston cores superimposed on boomer seismic profiles (2-6 kHz) showing the erosional contact at the regional unconformity (U) between Lake Winnipeg sediments above (light gray) and glacial Lake Agassiz sediments below (dark gray) (Todd et al., 1996, 1998, 2000). A dry crumbly zone characterizes the upper few decimeters of Lake Agassiz sediments in cores 221 and 201 but not 103. (B) Physical properties of cores showing enhanced magnetic susceptibility, bulk density, and shear strength in the surface zone of Lake Agassiz sediments at sites 221 and 201 (Todd et al., 2000; Moran and Jarrett, 1998) in association with the dry crumbly zone shown in (A) are attributed to desiccation. Site 103 (north-central northern basin) was always inundated and does not show attributes of desiccation (Todd et al., 1996; Moran and Jarrett, 1998). (C) Downcore oxygen isotope ratios (Todd et al., 1996) at site 103 for surface waters (algal cellulose in sediment organic matter, Buhay and Betcher, 1998) and average bottom waters (pore water) showing closed lake conditions prior to 4.7 ka (chronology based on paleomagnetic age determination in Table 4) when surface-water ratios differed most from those of average bottom water, indicating surface enrichment by periods of enhanced evaporation. Aquatic-cellulose enhanced δ^{18}O ratios record primary biological productivity in evaporatively -stressed surface waters, whereas pore water, whose isotope signals here resemble entrapped bottom water rather than inflowing groundwater, exhibits average paleo - lake-water δ^{18}O values (Todd et al., 1996; Buhay and Betcher, 1998).



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