HYDROLOGY AND WATER QUALITY OF UTAH LAKE

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ABSTRACT.— This paper summarizes hydrological and water quality findings from investigations by the authors and their colleagues over the past 10 years.

Water and salt balances on Utah Lake for the July 1970 to July 1973 period show both evaporation (342,077 ac-ft/yr) and groundwater (114,355 ac-ft/yr) to be somewhat larger than previously estimated by others.

The lake is eutrophic, turbid, and slightly saline, as might be expected in a shallow, basin-bottom lake in a semiarid area. Overall water quality in the lake is fair to good and appears to be controlled more by natural factors than by the activities of man. An increase in total dissolved solids (TDS) from about 300 mg/l in major surface and shallow groundwater inflows to about 900 mg/l in the main lake is the most significant water quality change. Of this TDS increase, about one-half results from evaporation of about one-half of the total inflowing water, one-quarter from salts carried by mineralized deep-spring inflows, and the remaining one-quarter from the poorer quality surface inflows to the lake.

Calcium carbonate (calcite) precipitation from the lake waters accounts for about 40 percent of the estimated 0.85 mm/yr (0.033 in/yr) long-term rate of sediment buildup of the lake bottom. This precipitated calcite is postulated to be an important turbidity source in the wave-stirred lake.

This paper presents information on the overall hydrologic features of Utah Lake, including the results of an intensive study of its water balance during the July 1970 to July 1973 period; it also presents information on the chemical and microbiological quality of both inflowing waters and the lake itself.

Utah Lake is a shallow lake with an average depth of 2.8 m (9.2 ft) at compromise water surface elevation of 1368.35 m (4489.34 ft) MSL. Its depth is very uniform more than 1 km (0.6 mile) offshore. At compromise level, in approximate percentages, 80 percent is deeper than 2.5 m (8.2 ft) but only 20 percent is deeper than 3.5 m (11.5 ft). Maximum depths of about 4.2 m (13.8 ft) occur in the south central portion of the lake west of Bird Island. Figure 1 gives area and volume of the lake as a function of surface water elevation.

When the shallow character of the lake is combined with the semiarid climate of the area, a large net evaporation loss occurs from the lake. The main impact of this evaporation is an appreciable increase in the concentration of total dissolved solids (TDS) in the remaining lake water. This evaporation impact is compounded by a large TDS load carried by mineralized springs that occur in the lake bed and near-shoreline areas. The resulting TDS concentration of some 900 mg/l in the lake proper is two to four times higher than the average TDS concentrations of most surface tributaries and groundwater inflows. TDS concentrations vary considerably both spatially and temporally with the temporal variation occurring both seasonally and with longer wet and dry hydrologic cycles. These longer cycles may result in a severalfold increase in TDS during drought cycles as com pared to wet cycles.

Background on Water Balance Methodology

The hydrology of a lake refers basically to identification and quantification of all elements of lake inflow and outflow—an accounting for all waters that enter and leave a lake. In a general sense, not relating to any particular lake, the inflows are all surface drainage (including drains, seeps, surface wash, intermittent inflows, well-defined tributaries, etc.), groundwater inflows (including seepage from saturated shoreline areas sometimes referred to as inflow from bank storage), and direct precipitation on the lake surface. The outflows include surface

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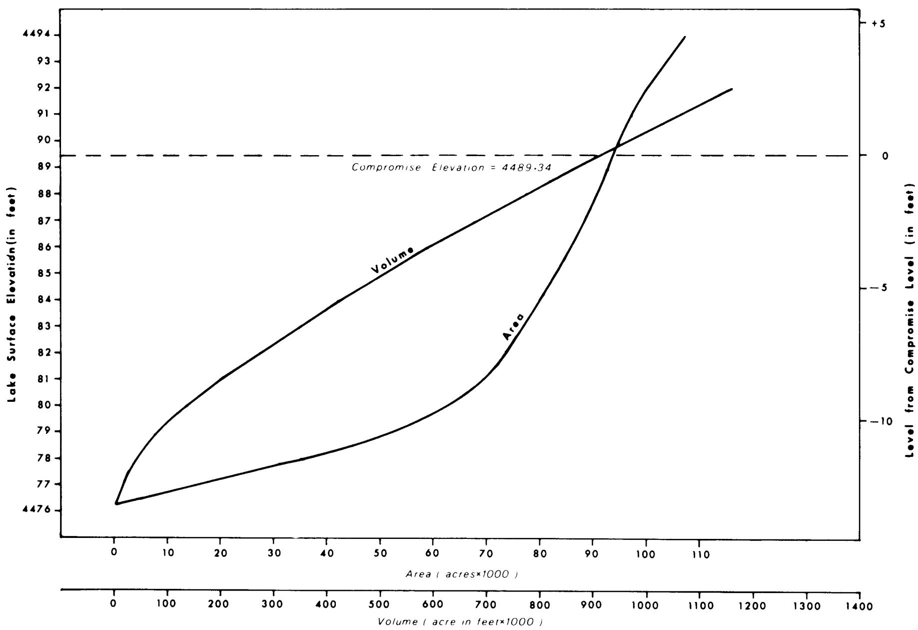

Fig. 1. Utah Lake area/volume curves as a function of elevation.

tributaries, groundwater seepage (including seepage into shoreline areas sometimes referred to as outflow to bank storage), evaporation from the lake surface, and transpiration from any vegetation growing in the lake.

The water balance is often stated as follows:

$$I_t + I_g + P - O_t - E = S \qquad (1)$$

in which I_t = the volume of water in all inflowing tributaries;
I_g = the volume of all inflowing groundwater;
P = the volume of precipitation on the lake surface;
O_t = the volume of water in all outflowing tributaries;
E = the volume of water evaporated from the lake surface; and
S = the volume of water represented by the rise or fall of the lake level;

or in other words, the difference between all inflows and outflows must be equal to the change in lake storage, which may be readily determined from lake level records. Since evaporation is difficult to measure accurately in the field, it is often calculated from the inflow-outflow equation. This calculation is referred to as a determination of evaporation by the water balance method.

UTAH LAKE WATER BALANCE STUDIES

Fuhriman et al. (1975) reported on Utah Lake water balance studies made over the period of July 1970 to July 1973. This section summarizes the key elements of that study, including refinements in those analyses and results that are first published herein.

The objective of the water balance studies was to provide an accurate determination of the evaporation from the lake by the use of equation 1. Previous studies by others on Utah Lake have not had sufficient data to make accurate water balance calculations on a monthly basis.[3] Intensive measurements of tributary inflow and increased coverage of precipitation during the 1970–73 period made it possible to make computations on a monthly basis during the April through October period, when evaporation was greatest and when evaporation pan data were also available.

[3]The studies reported herein make use of the water balance equation on a monthly basis except during the winter months—November through March—when factors such as freezing of the lake water introduce other variables into the relationship. Evaporation calculations by the water balance equation are, therefore, reported monthly from April through October and then one five-month period—November through March.

Water Balance Factors

Some hydrologic measurements relating to Utah Lake have been made on a continuing basis for many years. Others have been made intermittently, and some have been measured intensively over relatively short intervals of a few months or a few years in connection with particular studies. A discussion of measurements made and/or utilized in the analyses reported herein are described in the sections that follow.

Surface Inflow.— A total of 51 surface water inflows have been identified as contributing to the lake on a regular basis. The location and identification of these tributaries are given in Figure 2 and Table 1. Of these, two are measured on a continuous basis by the U.S. Geological Survey at points near to the lake—the Provo River and the Spanish Fork River. A few inflows are measured on a continuing basis by private or governmental units. During the late spring in 1970, measurement stations were established on tributaries where none existed and measurements were taken at one- to two-week intervals.

In spite of careful identification and measurement of the surface tributaries, there are times—such as during the spring thaw or during heavy precipitation on the lands immediately surrounding the lake—when it is not possible to measure all surface inflow. These inflows must be estimated.

Inflow quantities for all tributaries were measured and tabulated on a monthly basis for a two-year period. Measurements of the larger tributaries were continued for a third year, with the less significant tributary flows being estimated during the third year. A summary of the surface inflow measurements over the three-year period was reported by Fuhriman et al. (1975). These figures, with some minor adjustments that have resulted from refinements in the earlier evaluations, are given in Table 2.

Lake Outflow.—Surface outflows are continuously measured by the Jordan River commissioner. Records of these outflows—consisting of the Jordan River flow, the Utah and Salt Lake Canal, East Jordan Canal, the Utah Lake Distributing Company Canal, and the LDS Church Elberta Farm Pumping—were

TABLE 1. Utah Lake tributaries: identification codes and sampling points.

Station	Stream	MAG 208 stream code	Location
UT 01 & 02	Drain	Zu 01-00.10 & Zu 02-00.10	Combined UT 01 & UT 02—measured 100 yds below confluence, E side of Saratoga Rd at 6800 N
UT 03	Dry Creek	DRCL-00.31	0.10 mi E of jct of 9550 W and 7350 N
UT 04	Drain	Zu 04-00.29	0.20 mi E of jct of 9150 W and 7350 N at 9" flume
UT 05	Drain	Zu 05-00.38	Approx. 200 ft W of jct of 8730 W and 7350 N at 9" flume
UT 06	Drain	Zu 06-00.38	Approx. 50 ft S of jct of 8350 W and 7350 N at 12" flume
UT 07	Drain	Zu 07-00.43	At jct of 8000 W and 7350 N at 9" flume
UT 08	Lehi Sewage Treatment Plant and Drain	LEW 0-00.90	50 yds E of jct of 7800 W and 7550 N—approx 15 yds downstream from road. Includes effluents from Lehi WWTP.
UT 09	Mill Pond	SPCL 01.10	At jct of diversion works at 7400 W and 7750 N
UT 10	Drain	Zu 10-00.50	1.25 mi S of jct of 6500 W and 7750 N at small diversion gate. Includes effluents from American Fork WWTP.
UT 11	American Fork Sewage Treatment Plant	AFWT	About 0.55 mi S of jct of 6500 W and 7750 N

Table 1 continued.

Station	Stream	MAG 208 stream code	Location
UT 12	Drain	Zu 12-00.95	0.2 mi W and 1.0 mi S of jct of 100 W and 400 S at free-fall
UT 13	American Fork River	AMFR-0.90	0.75 mi N of American Fork Boat Harbor on 100 W at 9' wide concrete appurtenance
UT 14	Drain	Zu 14-00.38	0.1 mi W of jct of 6400 N and 5750 W
UT 15	Drain	Zu 15-00.59	0.1 mi E of jct of 6400 N and 5750 W
UT 16	Drain	Zu 16-00.40	0.25 mi S of jct of 6400 N and 5300 W at exit from 1' culvert
UT 17	Drain	Zu 17-00.80	0.25 mi W and 0.15 mi S of jct of 4850 W and 6400 N at bridge over concrete ditch
UT 18	Geneva Cannery Drain	LINH-00.38	15 yds S of jct of 4250 W and 5600 N at culvert under 4250 W. Includes effluents from Pleasant Grove WWTP.
UT 19	Drain	Zu 19-00.15	0.15 mi N of Geneva effluents recording station on W Geneva Road
UT 20	Geneva Steel Drain	Zu 20-00.14	Geneva Steel effluents recording station
UT 21	Drain	Zu 21-00.14	0.2 mi S of Geneva effluents recording station on W Geneva Road
UT 22	Drain	Zu 22-00.14	0.5 mi S of Geneva effluents recording station on W Geneva Road
UT 23	Drain	Zu 23-00.10	At 9" flume on drain 0.9 mi S of Geneva effluents recording station on W Geneva Road
UT 24	Drain	Zu 24-00.10	1.3 mi S of Geneva effluents recording station on W Geneva Road
UT 25	Drain	Zu 25-00.09	At 9" flume, 30 yds S of dirt road at jct of 4000 N and W Geneva Road
UT 26	Orem Sewage Treatment Plant	ORWT	S of WWTP at 2500 W and 1000 S
UT 27	Powell Slough	POWS-00.75	At 5' culverts at S end of slough on dike road. Includes effluents from Orem WWTP.
UT 28	Drain	Zu 28-00.10	On N Boat Harbor Drive, 1 mi W of jct of Geneva Road and N Boat Harbor Drive
UT 29	Provo River	PROR-02.82	At USGS gaging station 1300 ft W of bridge on W Geneva Road
UT 30	Drain	Zu 30-00.33	Discontinued—jct of 3110 W and 550 S
UT 31	Little Dry Creek	Zu 31-00.68	0.1 mi W and 0.25 mi S of jct of 560 S and 2470 W
UT 32	Drain	Zu 32-00.28	0.25 mi S and 250 ft W of jct of 1600 W and 1150 S
UT 33	Flowing Well	Zu 33-00.01	0.5 mi S of jct 1600 W and 1150 S and approx 50 ft N of culvert at Big Dry Creek near steel standpipe

Table 1 continued.

Station	Stream	MAG 208 stream code	Location
UT 34	Big Dry Creek	BDRC-01.52	0.5 mi S of jct of 1600 W and 1150 S
UT 35	11th West ditch	Zu 35-00.95	At jct of 1100 W and 1560 S on south side of road
UT 36	5th West ditch	Zu 36-00.85	0.5 mi S of jct of 1560 S and 500 W
UT 37	University ditch	Zu 37-00.50	0.25 mi S-SW in interchange of 1420 S and University Avenue
UT 38	Mill Race	MLCR 02.34	0.35 mi S of 350 E and 1500 S. Includes effluents from Provo WWTP.
UT 39	Provo Sewage Treatment Plant	PRWT	350 E and 1500 S
UT 40	Drain	Zu 40-00.25	Discontinued—S of Provo WWTP 0.35 mi and 0.27 mi E
UT 41	Rat Farm Drain	Zu 41-00.25	S of Provo WWTP 0.35 mi and 0.3 mi E—about 100 yds S of road near metal-fenced enclosure
UT 42	Steel Mill Drain	Zu 42-01.00	0.81 mi N of 2400 S and 1050 E (near Kuhni Packing Plant)
UT 43	Spring Creek	SPCS 01.51	0.3 mi N of 2400 S and 1050 E (0.55 mi S of Kuhni Packing Plant)
UT 44	Hobble Creek	HOBC 05.46	0.25 mi S of 2400 S and 0.15 mi W of frontage road at 21' weir. Includes effluents from Springville WWTP.
UT 45	Packard Drain	Zu 45-01.44	On frontage road 0.85 mi N or 3900 S, 5 yds downstream from culvert under highway
UT 46	Drain	Zu 46-02.18	0.35 mi W of freeway on 3900 S
UT 47	Dry Creek	DRCS-02.46	0.85 mi W of freeway on 4000 S at 9' wide gate. Includes effluents from Spanish Fork WWTP.
UT 48	Spanish Fork River	SPRF 01.30	At bridge 3.7 mi W of freeway on Hwy 79. Gaged at USGS station 2.5 mi N of Lake Shore (USGS moved 1979).
UT 48A	East Branch of Spanish Fork River		3.4 mi W of freeway on 4000 S at culvert under road
UT 49	Drain	Zu 49-01.89	At jct of Palmyra Drive and 3200 W (.8 mi N of 5200 S and 3200 W)
UT 50	Drain	Zu 50-01.14	At jct of 4000 W and 5200 S
UT 51	Benjamin Slough	BENS-02.94	0.2 mi E of jct 6000 W and 6400 S at bridge over slough. Includes effluents from Salem and Payson WWTPs.
UT 52	White Lake	WTLK-01.50	Goshen Bay channel—near 3' flume approx ¼ mi NW of White Lake on outlet channel to Goshen Bay
UT 53	Jordan River	JORR-48.45	At bridge on Hwy U-121, 2.3 mi SW of jct with Hwy 73

Italicized stations are "major" tributaries; these are defined as those generally carrying more than 2000 acre-feet of flow each year.

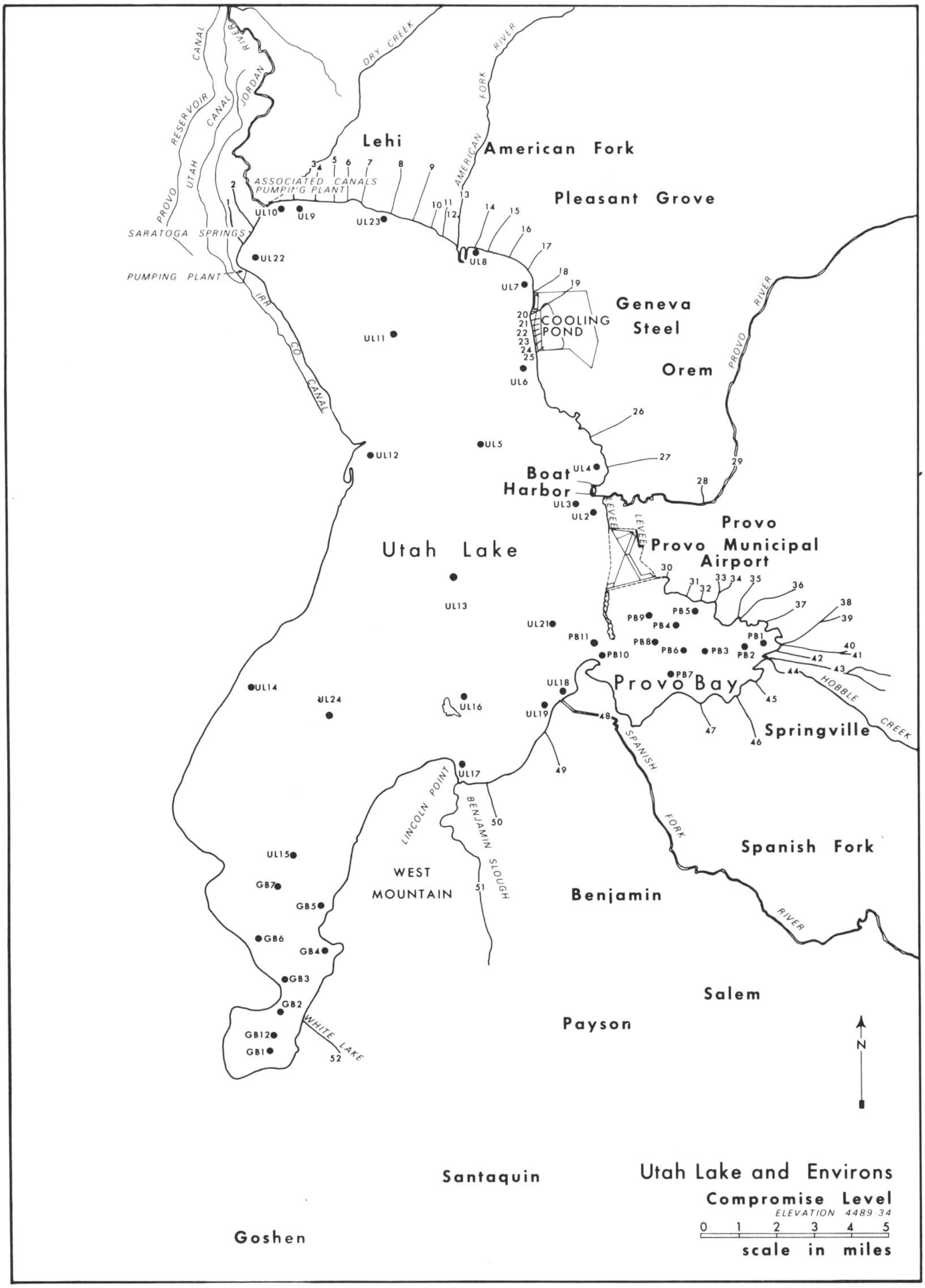

Fig. 2. Location and code numbers for Utah Lake sampling sites and code numbers of surface tributaries.

TABLE 2. Utah Lake surface tributary inflows, 1970–71 (all figures are in acre-feet of water, 1 acre-foot equals 1233.6 m^3).

Tributary number	1970 Jul	Aug	Sep	Oct	Nov	Dec	1971 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
1	44	33	57	26	0	0	0	0	0	17	16	3	196
2	46	25	24	45	0	0	0	0	0	0	2	19	161
3	0	0	0	0	0	0	0	0	0	7	59	37	103
4	24	28	23	32	30	33	33	33	34	32	34	35	371
5	23	13	37	7	20	16	21	30	14	18	23	67	289
6	138	126	234	69	55	67	73	66	64	73	104	146	1215
7	43	62	37	40	29	34	75	47	40	81	102	65	655
8	353	117	385	436	376	383	404	314	274	316	327	392	4077
9	1287	678	1240	1507	1642	1474	1519	1189	1207	1066	977	1363	15149
10	207	236	275	262	213	185	191	175	181	185	240	269	2619
11	163	129	95	83	74	74	74	76	80	80	117	215	1260
12	64	58	99	80	61	54	60	47	35	61	136	154	909
13	58	67	45	52	44	26	23	21	23	25	49	501	934
14	148	163	153	155	126	109	120	102	109	128	125	226	1664
15	157	156	153	195	174	155	156	138	156	163	191	189	1983
16	143	73	118	119	99	93	111	111	122	124	146	152	1411
17	401	255	356	319	222	156	158	131	159	235	368	472	3232
18	1444	1569	2686	2442	2081	1866	2115	1725	1819	1974	1673	1519	22913
19	1	3	0	0	0	0	0	0	0	0	0	0	4
20	1842	2027	1849	1910	2170	2165	2196	1741	1910	2006	1910	1805	23531
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	8	8	6	6	4	2	0	34
23	0	0	0	0	4	6	6	6	6	6	5	2	41
24	12	8	11	17	20	19	22	17	16	15	13	13	183
25	67	98	58	59	82	94	119	88	85	23	72	89	934
26	314	313	289	252	296	217	202	199	225	217	252	260	3036
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
28	7	0	28	35	68	67	182	129	79	87	47	28	757
29	1250	633	1220	9500	20700	23350	19280	17170	13310	18800	11690	19500	156403
31	78	121	164	149	177	160	116	106	119	143	118	66	1517
32	49	44	44	45	42	43	43	39	43	46	47	55	540
33	6	6	6	7	7	7	7	7	6	6	6	6	77
34	743	722	717	669	595	410	337	269	296	358	394	702	6212
35	91	92	199	118	149	132	93	99	45	65	82	75	1241
36	32	64	138	50	26	13	40	130	25	38	76	88	720
37	74	84	94	93	82	63	58	54	58	75	83	72	890
38	867	870	814	1041	1118	1041	990	898	1208	1031	814	825	11517
39	1524	1564	1361	812	948	928	935	828	853	1014	1182	1342	13291
40	232	229	185	247	236	208	184	166	184	167	170	148	2356
41	408	423	416	337	263	273	292	298	346	378	498	461	4393
42	1484	1403	1362	1708	1782	1568	1602	1390	1228	1274	1858	1297	17956
43	743	373	359	278	293	404	673	634	817	923	921	729	7147
44	145	128	758	1366	2002	2049	1979	1834	2178	2731	2012	557	17739
45	170	205	207	226	242	229	209	213	183	140	154	281	2459
46	494	577	422	267	176	217	178	164	178	194	227	523	3617
47	334	924	1134	1361	1211	1291	1211	1158	1215	1159	399	791	12188
48	453	681	2165	4130	5320	5810	6810	6810	9970	13860	10760	1910	68579
49	68	69	56	57	50	34	32	42	44	37	35	58	582
50	261	331	256	288	245	272	303	368	242	277	395	434	3672
51	1454	1645	3242	3454	3944	3885	3516	3706	3933	4233	2881	2159	38052
52	0	0	0	0	800	200	538	931	720	354	338	70	3951
UTI[a]									3000	2000	1000	1000	1000
TOTALS	19056	18695	24811	35725	49734	51308	48794	45185	48385	57696	44661	42490	486540

[a]UTI denotes unmeasured tributary inflow.

Table 2 continued.

Tributary number	1971 Jul	Aug	Sep	Oct	Nov	Dec	1972 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
1	0	4	15	10	0	0	0	0	0	0	25	8	62
2	0	5	23	0	0	0	0	0	0	0	68	1	97
3	0	0	0	0	0	0	0	0	49	0	0	60	109
4	38	35	22	26	31	32	31	35	30	23	33	39	375
5	22	2	19	15	29	0	37	21	17	12	20	32	226
6	159	115	215	63	64	70	74	63	55	60	112	146	1196
7	68	79	135	194	191	97	92	58	30	57	179	74	1254
8	276	93	298	328	343	310	295	230	178	214	406	351	3322
9	1387	997	1445	1558	1418	1311	1291	1104	1168	916	375	1154	14124
10	215	207	220	217	204	180	178	16	213	274	325	233	2482
11	259	141	107	76	74	77	70	66	70	92	104	164	1300
12	73	96	121	114	90	72	49	38	50	100	168	178	1149
13	63	60	58	57	58	60	61	58	68	83	105	173	904
14	158	231	167	159	133	114	105	89	86	121	149	168	1680
15	123	106	158	178	163	151	129	115	121	135	150	177	1706
16	99	103	98	115	98	94	80	71	90	83	121	114	1166
17	348	377	428	378	249	171	141	123	117	179	375	506	3392
18	1374	1678	2693	2466	2020	1863	1654	1377	1353	1452	1150	1410	20490
19	1	3	0	0	0	0	0	0	0	6	0	0	10
20	1933	1980	2538	2266	2289	2440	2753	2377	2541	2509	2440	2313	28349
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	6	6	6	6	12	30	6	0	72
23	0	0	0	0	6	6	6	6	7	7	6	1	45
24	10	13	11	16	21	18	16	15	16	15	15	13	179
25	107	90	45	66	82	103	92	73	61	54	100	78	951
26	262	292	273	245	226	279	290	257	265	266	312	312	3279
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
28	17	3	50	75	122	123	111	104	80	12	55	23	775
29	850	877	1120	15802	20229	20205	16520	16228	20577	16854	16723	29437	175482
31	104	100	149	137	105	109	123	104	74	89	68	65	1227
32	42	45	40	42	39	42	43	40	49	42	80	125	629
33	3	6	6	6	6	6	7	7	7	7	8	8	77
34	617	354	297	470	242	224	234	224	289	321	301	321	3894
35	46	54	119	211	214	133	148	35	80	125	141	119	1425
36	25	24	60	58	26	30	31	23	25	71	25	24	422
37	75	80	92	95	76	55	49	35	37	60	68	69	791
38	859	947	711	883	868	923	959	892	1008	726	750	684	10210
39	1439	1624	1401	1259	1117	1055	952	944	1128	1141	1325	1466	14851
40	404	255	273	206	169	149	123	29	31	30	18	0	1687
41	313	262	241	245	228	208	215	196	246	303	240	250	2947
42	1529	2057	2116	2241	1940	1468	1279	1294	1457	1743	2060	2338	21522
43	451	414	438	476	468	509	553	506	553	553	584	779	6284
44	149	191	434	1461	1663	1766	168	1818	2226	2130	92	161	14059
45	341	279	331	424	643	401	357	276	283	315	240	268	4158
46	386	456	274	216	203	191	185	127	178	202	240	292	2950
47	489	835	891	941	1073	823	935	1041	1992	1095	689	238	11042
48	593	538	1700	5343	6389	7289	7329	7525	10320	6926	801	736	55489
49	62	54	39	45	44	40	31	35	37	54	49	48	538
50	333	250	207	180	137	135	172	150	160	184	394	303	2605
51	1042	1156	2559	3063	3793	4013	4034	3664	3419	2600	1636	2172	33152
52	0	0	0	0	200	300	314	713	680	300	90	0	2597
UTI	0	0	0	0	0	8000	0	0	0	0	0	0	8000
TOTALS	18355	18838	23877	43806	49229	57071	45592	43748	53073	44021	34951	48951	481512

Table 2 continued.

Tributary number	1972 Jul	Aug	Sep	Oct	Nov	Dec	1973 Jan	Feb	Mar	Apr	May	Jun	Totals Jul–Jun
9	1537	1168	1309	1875	1666	1722	1506	1722	1968	1785	1107	1368	18733
11	129	124	138	143	130	135	143	130	130	140	150	150	1642
18	1599	1568	2410	2767	2350	1875	1783	1805	2029	1577	1844	1785	23392
20	1745	2372	2313	2593	2602	2579	2782	2250	2271	2063	2265	2405	28240
26	314	314	304	295	285	295	295	266	333	313	285	304	3603
27	1210	1270	1240	1380	1440	1420	1500	1480	1540	1450	1530	1320	16780
29	1840	732	2020	11400	13850	14090	16290	16000	17130	20680	41880	19470	175382
34	679	710	533	429	235	191	188	204	334	502	875	1154	6034
38	813	695	632	943	683	1185	1319	1206	1395	1325	678	546	11420
39	1475	1427	1381	1269	933	1135	1009	945	1094	1068	1465	1427	14628
41	286	455	550	524	529	336	240	272	340	374	460	387	4753
42	1020	1072	775	1161	1651	740	526	461	1055	1104	1423	1214	12202
43	861	829	439	689	455	252	144	218	375	371	383	980	5996
47	85	221	416	1072	1133	1156	1128	1137	1270	1187	893	119	9817
48	113	149	762	4950	6320	6450	6550	5730	7300	17090	40150	3480	99044
51	440	336	857	2413	2657	2619	2828	3307	3590	3273	3951	2023	28294
52	0	0	0	500	600	700	1200	1200	700	500	250	35	5685
UTI	3721	3416	4331	4929	5134	5278	8900	16700[a]	10912	8153	36779	17304	125557
TOTALS	17867	16858	20410	39332	42653	42158	48331	55033	53766	62955	136368	55471	591202

[a]In February abnormal winter thaw caused considerable unmeasured runoff.

obtained from Commissioner Brad Gardner. Outflows were tabulated on a monthly basis.

Precipitation.— Precipitation on the lake represents inflow to the lake. Precipitation from July 1970 through April 1971 was measured at the regular U.S. Weather Bureau stations at Provo (KOVO Radio Station), Pleasant Grove, Lehi, Geneva Steel Company, Payson, and Elberta. Beginning in the month of April 1971, additional measuring stations were established at Pelican Point, Dixon Farms, Lakeshore, and Provo airport. The areal distribution of precipitation on the lake surface was determined by using the Thiessen method of weighted distribution. Total lake surface precipitation was tabulated on a monthly basis.

Change in Storage.— Calculation of water balance elements on a monthly basis requires determination of storage volume at the end of each month. A lake water stage recorder is maintained and operated by the Jordan River Commissioner. The water level charts indicate that wind can cause considerable fluctuation—more than 0.6 m (2 ft) at times—in the water level of the lake. Carefully analyzing wind-caused seiches and averaging high and low water levels during such oscillations allowed correction to an accurate end-of-month lake stage.

Ground Water Inflow and Outflow

The geology of Utah Valley (Hunt, Varnes, and Thomas 1953, Bissell 1963) is such that the area surrounding Utah Lake—and the lake itself—is underlain with low-pressure artesian aquifers. In addition, the water table in the unconsolidated shallow deposits near the lake almost always has a gradient toward the lake. Under these conditions, there is obviously groundwater inflow to the lake from a number of different geologic formations. Based on geologic characteristics of Utah Valley, groundwater outflow from the lake is felt to be negligible.

Springs in the Lake.— It has long been known that a number of springs flow directly into the lake from its bed. Evidences of extensive spring flows into the lake have been noted by Swendsen (1905), Richardson (1906), Hunt et al. (1953), Bissell (1963), and Mundorff (1970, 1971), who wrote of the existence of such springs and of the general geologic features of the lake that caused the springs.

Several attempts have been made to measure the flow of the springs. Harding (1941) made observations over a period of several years and also accumulated information obtained from interviews with others relating to springs in the lake. Viers (1964) made detailed studies of lake springs in an attempt to determine their effect on the lake's chemical quality; he made observations from the air and ground to locate spring areas and then sampled them for quality determinations. He located and identified 30 separate springs in the lake. Milligan et al. (1966) made careful observations, including a number of measurements of both quantity and quality, of the nearshore springs flowing into the lake. Hansen (1975) reports observations of many springs above the water line during the 1934–35 drought, when the lake was at its lowest historical level. Dustin and Merritt (1980) considered the hydrogeology of the lake with emphasis on Goshen Bay and concluded that between 12.3 and 22.2 $\times$ $10^6 m^3/yr$ (10,000 to 18,000 ac-ft/yr) of groundwater is coming from Cedar Valley into the southern end of the lake.

There are many springs in the lake, but it is obvious that field measurement of this source of inflow is virtually impossible. Since it was necessary to input this element as a known quantity in the water balance equation, an indirect method quantifying this inflow was used to supplement the limited amount of spring flow data available. This method was the use of salt balances as described later.

Evaporation

Measurements of evaporation from a U.S. Weather Bureau Class A evaporation pan have been made during the summer months at the Utah Lake pumping station southwest of Lehi for 28 years. The record of these measurements is published in the monthly *Climatological Data for Utah*, published by the U.S. Weather Service.

However, evaporation from standard pans is different than evaporation from nearby lakes themselves, and the degree of difference depends upon many factors. In fact, accurate determination of evaporation from a lake is a very difficult problem since some elements of inflow and outflow are almost impossible to measure accurately.

The most intensive study of evaporation from a lake surface ever undertaken was conducted at Lake Hefner, Oklahoma, in 1950 and 1951. Harbeck et al. (1952, 1954) reported results of this intensive evaporation study involving many emminent scientists and engineers. Many detailed measurements and evaluation methods were used to determine the evaporation from this carefully selected lake. Prior to this study, lake evaporation was generally estimated by multiplying the pan evaporation by a coefficient that usually was between 0.7 and 0.8. These values were based mainly on work by Rohwer (1931), Harding (1935), and Young (1947).

A number of publications reporting on extended Lake Hefner investigations have been issued. Harbeck (1962) wrote on the use of the mass-transfer theory. Kohler et al. (1955) and Kohler and Parmele (1967) reported on studies using evaporation pans and meteorological factors such as solar radiation, air and water temperature, and dew point temperature to develop charts that might be used at other locations to estimate evaporation. Extending these studies to specific locations in the U.S., Kohler et al. (1959) published generalized maps for the U.S. to provide a basis for evaporation estimates. These maps are based upon empirically derived charts utilizing the meteorological factors mentioned above.

The results of measurements at Lake Hefner reported by Harbeck et al. (1952) showed clearly that the average pan coefficients for the Class A evaporation pans varied from month to month. Neglecting one month, in which there was apparently some sort of observation error, the coefficients ranged from about 0.4 to 1.32. The low values occurred in the spring of the year when the lake water temperature was lower than the pan water temperature, and the high values occurred in late summer and fall when the reverse was true.

Previous evaporation studies on Utah Lake.— Various studies in the past have resulted in estimates of evaporation from Utah Lake. Swendsen (1904) reported use of an evaporation pan at Lehi as early as 1901 in studies by the Salt Lake City engineer to estimate Utah Lake evaporation. Jacobsen and Peterson (1932) reported on studies that included evaporation estimates. Harding (1940) analyzed the available evaporation pan records near Utah Lake over the period 1903 to 1936 to develop estimates of evaporation from the lake. He used a constant value of 0.70 for a pan coefficient and then used the Lehi record, extending it by various statistical comparisons with other records.

In connection with the development of a water resources management simulation model for the Upper Jordan River drainage area, Wang et al. (1973) studied the water balance of Utah Lake. In conjunction, Wang and Riley (1973) also estimated evaporation by the energy budget analysis, even though the necessary measurements of solar radiation, vapor pressure, and water temperatures were not available at Utah Lake. They pointed out the error in the common practice of assuming a constant coefficient of pan evaporation compared to lake evaporation. Using their evaporation estimates in the water budget analysis in the simulation of lake levels using their simulation model, they achieved a good correspondence between actual and simulated lake levels. However, it should be pointed out that they used a water budget analysis that included estimated values for both groundwater inflow and evaporation. These are both unknowns and error in one could be offset by the same magnitude of error in the other. The report of Wang and Riley (1973) includes a plot of simulated lake evaporation versus pan evaporation at Lehi. This graph results in an S-shaped curve indicating low values of the pan coefficient during months when the lake evaporation is either in the low or the high range. This seems to be inconsistent with the Lake Hefner studies (Harbeck et al. 1952 and 1954), which indicated that pan coefficients were low in the spring and early summer when lake water temperatures were low relative to the overlying air and high in the late summer and fall when the lake waters had stored a significant amount of heat.

The U.S. Bureau of Reclamation (1964), in planning for the Bonneville Unit of the Central Utah Project, used a constant evaporation pan coefficient of 0.8 applied to the evaporation pan records at Lehi in making estimates of total lake evaporation. Viers (1964) also used a constant pan coefficient of 0.8 applied to the Lehi evaporation pan record to estimate the lake evaporation.

Salt Balance Studies

All water balance factors were measured with reasonable accuracy except evaporation and groundwater inflow. Therefore, using the water balance equation alone, it was not possible to determine evaporation by this method. However, additional physical facts aid in the evaluation of evaporation: (1) evaporation is known to be relatively small during the winter months, (2) groundwater inflow from deep-seated sources is relatively constant, (3) groundwater inflow from other than deep-seated sources is related to groundwater levels around the periphery of the lake, and (4) some of the mineral ions dissolved in the lake waters are sufficiently stable that an ion-balance (salt balance) analysis can provide an additional check on water quantity estimates.

The theory of the ion-balance analysis is simple. In effect, it is a mass balance, the same as a water balance, on selected dissolved minerals in the waters. Ions are chosen that do not ordinarily precipitate out of solution (conservative ions) at the concentrations found. Ion concentrations in all incoming and outgoing waters are used in an equation similar to the water balance equation. Ion concentrations must be determined for each inflow and outflow over time. In many cases, this may be more difficult than obtaining accurate water inflow and outflow data required for both water-balance and ion-balance calculations. In the case of Utah Lake, two factors are present that make ion-balance calculations feasible: (1) the mineralized spring inflows contain a much larger proportion of sodium, potassium, sulfate, and chloride ions than do most surface and fresh groundwater inflows. Since a large uncertainty is associated with the total annual volume of these mineral inflows, this large difference in ion concentrations is extremely helpful in adjusting the magnitudes of fresh and mineralized groundwater inflows as trial water and ion balances are run; (2) a substantial amount of chemical quality information is available on the major tributary inflows, fresh groundwaters, and major mineralized inflows, as well as for the Jordan River.

The water quality simulation model (LKSIM), developed in the study of the effects of lake diking on water quality (Fuhri-

TABLE 3. Water budget analysis—Utah Lake 1 July 1970–30 June 1973 (all figures are in acre-feet of water, 1 acre-foot equals 1233.5 m^3).

Month	Precipitation on lake surface	Surface inflow	Shallow subsurface inflow	Deep Subsurface inflow	Surface outflow	Change in storage	Calculated evaporation
1970							
Jul	7,234	19,056	6,500	2,324	45,841	- 66,231	55,594
Aug	6,080	18,695	8,500	2,324	51,332	- 76,792	61,058
Sep	15,860	24,811	5,700	2,324	33,876	- 26,371	41,191
Oct	9,696	35,725	5,400	2,324	14,862	+ 14,187	24,096
Nov	19,540	49,734	6,200	2,324	8,896		
Dec	12,538	51,308	6,600	2,324	16,942		
1971							
Jan	6,102	48,794	6,800	2,324	23,096	+ 200,159[a]	34,916[a]
Feb	11,925	45,185	6,500	2,324	25,904		
Mar	2,987	48,385	7,000	2,324	31,305		
Apr	16,557	57,696	6,400	2,324	30,042	+ 27,519	25,415
May	3,815	44,661	5,800	2,324	38,586	- 22,775	40,789
Jun	2,522	42,490	4,700	2,324	40,282	- 45,024	56,778
TOTAL	114,946	486,540	76,100	27,888	360,964	+ 4,672	339,837
1971							
Jul	817	18,355	6,500	2,324	48,424	- 84,513	64,085
Aug	5,223	18,838	9,500	2,324	52,045	- 74,649	58,489
Sep	5,860	23,877	14,700	2,324	37,200	- 29,899	39,450
Oct	10,327	43,806	9,500	2,324	13,185	+ 38,921	13,852
Nov	7,783	49,299	6,200	2,324	10,322		
Dec	10,426	57,071	6,600	2,324	15,211		
1972							
Jan	277	45,592	6,800	2,324	23,790	+ 176,301	33,729[a]
33,729[a]							
Feb	133	43,748	6,500	2,324	25,791		
Mar	2,429	53,073	7,000	2,324	29,334		
Apr	9,177	44,021	6,400	2,324	26,079	+ 3,742	32,101
May	326	34,951	5,800	2,324	44,952	- 50,356	48,805
Jun	5,278	48,951	8,700	2,324	44,488	- 32,229	52,994
TOTAL	58,056	481,512	94,200	27,888	370,821	- 52,672	343,505
1972							
Jul	985	17,867	14,500	2,324	51,740	- 90,579	74,515
Aug	4,726	16,858	12,500	2,324	52,567	- 75,494	59,335
Sep	5,258	20,410	6,700	2,324	35,800	- 42,894	41,786
Oct	19,106	39,332	5,400	2,324	13,464	+ 35,247	17,451
Nov	6,442	42,653	6,200	2,324	5,286		
Dec	4,808	42,158	6,600	2,324	1,773		
1973							
Jan	7,338	48,331	6,800	2,324	6,779	+ 236,673[a]	24,917[a]
Feb	7,147	55,033	6,500	2,324	19,714		
Mar	9,499	53,766	7,000	2,324	26,753		
Apr	11,727	62,955	6,400	2,324	29,798	+ 29,999	23,609
May	8,865	136,368	5,800	2,324	39,690	+ 65,849	47,817
Jun	6,148	55,471	4,700	2,324	44,969	- 29,786	53,460
TOTAL	92,049	591,202	89,100	27,888	328,333	+ 129,015	324,890
1970–73 ANNUAL AVERAGE	88,350	519,751	86,467	27,888	353,373	—	342,077

[a]Five month total

man et al. 1975), was used to achieve the results reported herein. Sodium and potassium cations and chloride and sulfate anions were used as the primary ions in the ion-balancing procedures. The process actually involved successive approximations to find the quantity of groundwater of particular ion concentrations, which would result in a good simulation when compared to the measured concentrations in the lake. The resulting "final" water balance is given in Table 3 and a summary of the evaporation results in Table 4. It is noteworthy that the pan coefficient (the calculated lake evaporation divided by the pan evaporation) is relatively low in the spring and increases throughout the summer. This pattern is consistent with the Lake Hefner results reported by Harbeck et al. (1952).

These simulation studies also resulted in an estimated groundwater input of 141 × $10^6 m^3/yr$ (114,355 ac-ft/yr). Others have estimated this inflow to be much smaller—perhaps 37 × 10^6 to 56 × $10^6 m^3$ (30,000 to 45,000 ac-ft/yr) (Harding 1941).

Discussion of Water Balance Results

Over the three-year period of the study, loss by evaporation was over 1250 × $10^6 m^3$ (1,026,000 ac-ft)—an average annual loss of more than 417 × $10^6 m^3$ (342,000 ac-ft). Evaporation was equal to 66 percent of the surface tributary inflow and 47 percent of the total inflow. Groundwater flow directly into the lake was calculated to be 16 percent of the total inflow and 22 percent of the surface tributary inflow.

TABLE 4. Calculated evaporation[c] from Utah Lake and evaporation from pan at Lehi, Utah, 1 July 1970–30 June 1973.

Month	Average lake area (acres)	Calculated lake evaporation[a,b] (acre-feet)	Calculated lake Evaporation (inches)	Pan Evaporation (inches)	Pan coefficient
1970					
Jul	92,018	55,594	7.33	9.39	0.78
Aug	89,940	61,058	8.21	8.82	0.93
Sep	88,467	41,191	5.58	6.20	0.90
Oct	88,292	24,096	3.25	3.47	0.94
1971					
Apr	94,772	25,415	3.20	5.16	0.62
May	94,843	40,789	5.18	6.57	0.79
Jun	93,817	56,778	7.32	9.16	0.80
Jul	91,890	64,085	8.48	10.88	0.78
Aug	89,578	58,489	7.89	9.06	0.87
Sep	88,096	39,450	5.37	6.84	0.79
Oct	88,222	13,852	1.86	no data	—
1972					
Apr	93,982	32,101	4.10	5.17	0.79
May	93,284	48,805	6.33	8.87	0.71
Jun	92,052	52,994	6.94	9.01	0.77
Jul	90,270	74,515	10.01	11.72	0.84
Aug	87,914	59,335	8.16	8.73	0.93
Sep	83,162	41,786	5.86	6.04	0.97
Oct	86,055	17,451	2.41	no data	—
1973					
Apr	93,900	23,609	3.00	4.32	0.69
May	95,360	47,817	5.95	8.23	0.72
Jun	95,910	53,460	6.72	8.97	0.75

[a]Calculated by the combined ion balance and water budget method.
[b]The evaporation pans were taken out of service during winter.
[c]Author's note—Information from very recent 1930–79 lake simulation work indicates lake evaporation to be about 10 percent higher than given in this table.
1 acre = 0.4047 hectares
1 acre-foot = 1233.5 cubic meters
1 inch = 0.02540 meter

The average evaporation pan coefficients for the summer months are as follows:

April	0.70
May	0.74
June	0.77
July	0.80
August	0.91
September	0.89

The average monthly winter evaporation for November through March was 0.0206 m (0.81 in) per month.

Lake evaporation as determined by these studies is greater than has been estimated by previous investigators. At least two significant factors are believed to contribute to the abnormally high evaporation loss from Utah Lake: (1) the shallowness of the lake, which results in the lake contents being more easily raised in temperature than would be the case with a deeper lake, and (2) the wind-caused seiches on the lake (frequent and often as much as 0.6 to 0.9 m (2 or 3 ft), which wet a large area of the shore in the southern part of Goshen Bay with every rise of the water surface. A large amount of evapotranspiration subsequently occurs from these areas.

Utah Lake Water Quality

Tributary Quality

Water that flows into Utah Lake originates from a natural drainage area of more than 7550 km^2 (2900 mi^2). Dwelling in this watershed area is a 1980 population of about 200,000 people, large numbers of wild and domestic animals, and many industrial and commercial establishments—all contributing wastes that affect Utah Lake. However, a large part of the natural and man-made pollution is assimilated in the drainage and lake system such that harmful effects to the lake are less than might be anticipated.

Table 5a gives average temperature and chemical quality data for the larger tributaries for which significant amounts of data are available (see Fig. 2 for tributary location). Data are mainly from the 1970–73 period. More recent data, particularly for 1977–1980, are not included, but cursory review of these more recent data show no substantial differences. From zero to 10 data values were available for each parameter each month; usually 2 or 3 in the winter months and 5 or 6 in the summer months. The values are simple averages; no attempt was made to flow-weight or smooth-out the data. The tabulated data are presented in the same format as the lake quality data in Table 7 to facilitate comparisons.

Tributary temperatures are generally about the same as lake temperatures, except in June when late spring runoff waters are 6 to 7 C colder and during the winter months when tributaries are several degrees warmer than the lake.

Tributary total dissolved solids (TDS) values of some 250 to 1000 mg/l may not appear significantly lower than the 800 to 950 mg/l in the main lake, but inspection of the tributary flow volumes in Table 5b shows that the major inflows—UT13 (American Fork River), UT29 (Provo River), UT44 (Hobble Creek), UT48 (Spanish Fork River)—contain only 250 to 500 mg/l TDS. Of particular note is the Provo River, which carries average TDS values of less than 300 mg/l. The Provo River carries about 30 percent of the total inflow to Utah Lake, but only about 14 percent of the TDS. Other quality parameters given follow about the same pattern relative to the lake quality as do the TDS values.

Tributary flow rate values given in Table 5b are for 1979, a year closer to average than the 1970–1973 values in Table 2.

Lake Water Quality

Public consensus would likely classify Utah Lake as badly polluted. However, scientific investigations show this is not true, if we define pollution as the quality degradation resulting solely from the activities of man.

It must be recognized what Utah Lake is: a basin-bottom lake, the natural recipient of many "pollutants" from its drainage basin; a lake adjoined by marshlakes on its east and south fringes, where most people use the lake; a lake where evaporation removes about one-half the total inflowing water, thus doubling the mean salt concentration; and a shallow lake where sediments are stirred and mixed by wave action, giving the lake a milky gray to gray brown, turbid appearance.

Most man-caused pollutants enter in tributaries on the east and south of the lake and

TABLE 5a. Average water quality values for selected Utah Lake tributaries.[a]

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature—C												
UT 9	3.7	6.9	10.5	11.3	14.9	–	26.0	23.2	20.6	8.8	6.5	4.0
UT13	–	–	12.6	10.7	17.5	17.0	–	19.2	16.6	–	–	–
UT18	5.8	6.7	10.8	10.3	15.6	15.0	23.2	22.6	21.9	9.9	8.2	4.2
UT29	4.0	3.6	5.9	8.0	11.5	14.3	25.0	19.6	18.6	7.8	7.4	4.7
UT34	6.4	7.8	10.5	11.9	15.1	14.5	17.8	19.7	20.2	9.6	10.7	7.0
UT38[b]	–	–	9.5	–	16.5	15.9	–	16.5	–	–	–	–
UT42	8.9	9.0	15.5	14.3	17.4	–	–	19.8	18.0	15.6	12.2	–
UT43	4.8	8.3	12.7	11.9	17.9	14.0	19.8	18.0	18.3	8.2	8.9	6.5
UT44	8.2	6.6	7.6	7.7	15.0	14.0	–	18.6	20.9	10.0	8.9	–
UT45	5.0	8.0	–	12.4	–	–	18.0	20.9	22.1	8.8	8.5	6.5
UT47	2.2	6.1	10.4	10.2	15.3	–	–	21.8	19.9	10.6	7.8	3.3
UT48	3.9	4.7	6.5	8.8	13.5	16.0	23.2	20.4	18.1	6.0	5.8	1.9
Total dissolved solids—mg/l												
UT 9	444	444	388	472	373	–	411	472	431	410	414	453
UT13	–	–	398	341	–	259	–	363	332	–	–	–
UT18	560	587	626	618	582	478	562	528	514	507	541	513
UT29	327	271	325	327	245	227	274	289	263	249	257	272
UT34	416	398	453	445	380	364	373	443	371	391	377	378
UT38[b]	–	–	378	372	405	387	386	890	394	356	890	–
UT42	798	716	718	741	670	–	–	1065	684	729	699	–
UT43	624	582	615	580	561	438	548	627	632	570	599	654
UT44	356	278	327	259	316	335	–	460	–	310	294	–
UT45	957	1150	886	958	–	–	496	552	–	692	748	839
UT47	937	1016	991	1086	778	–	–	–	–	851	873	–
UT48	552	490	535	480	496	437	722	906	486	526	494	505
UT51	841	912	883	861	1154	1405	1080	1113	857	825	841	1017
Calcium—mg/l												
UT 9	78.5	75.0	74.2	61.9	69.0	70.3	81.0	56.0	74.7	66.0	77.0	–
UT13	–	–	84.5	53.2	72.0	59.8	–	82.3	79.0	–	–	–
UT18	94.5	89.0	98.0	85.7	86.0	83.2	98.5	88.0	92.0	76.0	91.5	–
UT29	66.5	59.5	65.8	60.2	55.5	52.1	62.0	60.7	63.2	56.0	56.8	60.7
UT34	93.3	85.0	83.8	75.7	87.3	85.2	95.5	50.0	84.0	91.0	86.0	–
UT38[b]	–	–	69.0	–	71.0	74.2	85.0	100.0	77.0	88.0	85.0	–
UT42	125.0	133.0	113.0	116.0	137.0	–	–	–	122.0	132.0	132.0	17.0
UT43	107.0	111.0	102.0	97.3	109.0	98.5	99.0	84.0	98.0	82.5	107.0	–
UT44	72.7	69.7	66.2	53.8	44.0	65.9	–	78.0	75.0	73.0	88.0	68.0
UT45	–	98.0	93.0	66.8	75.0	87.7	82.0	43.0	81.0	–	82.5	–
UT47	86.0	83.0	72.8	54.8	70.0	–	–	–	–	87.0	86.0	–
UT48	84.7	81.0	72.2	60.3	62.5	65.9	73.8	80.8	68.2	–	77.4	83.5
UT51	102.0	78.0	76.5	64.9	82.0	89.0	92.5	69.0	76.0	85.0	70.6	–
Magnesium—mg/l												
UT 9	19.7	40.3	38.0	36.4	37.7	34.3	37.0	30.0	38.7	36.0	37.2	–
UT13	–	–	29.7	22.8	27.0	17.9	–	25.3	27.0	–	–	–
UT18	42.0	32.0	45.3	39.7	39.3	39.0	44.5	37.0	39.7	38.0	40.8	–
UT29	16.5	16.5	15.4	14.7	18.5	11.1	15.0	14.8	16.8	13.7	14.5	11.7
UT34	21.3	21.5	20.6	20.3	20.0	20.8	22.5	19.0	20.7	21.0	22.8	20.0
UT38[b]	–	–	22.0	–	22.0	21.4	16.0	25.6	18.5	12.0	21.0	–
UT42	43.7	43.5	41.7	37.7	41.0	–	–	–	38.0	41.0	40.0	54.0
UT43	42.0	30.0	31.4	33.8	29.3	29.0	34.5	30.0	44.0	35.0	33.0	–
UT44	14.0	17.2	16.5	10.0	11.0	18.4	–	34.0	25.0	18.0	15.8	16.0
UT45	–	68.0	60.0	42.8	43.0	41.0	33.5	54.0	48.0	–	53.0	–
UT47	54.0	50.0	49.8	33.6	39.5	–	–	–	–	51.0	50.0	–
UT48	30.7	34.0	30.4	25.7	32.0	30.4	54.7	49.2	25.8	–	28.8	31.3
UT51	67.0	66.0	56.0	59.0	83.0	83.0	86.0	81.0	60.0	65.0	64.0	–

Table 5a continued.

					Temperature—C							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Sodium—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	20.0	23.3	28.4	23.6	24.7	18.3	39.5	22.0	19.7	17.0	20.2	–
UT13	–	–	30.5	15.3	29.0	36.1	7.2	12.3	13.0	–	–	–
UT18	33.0	27.5	40.9	39.3	36.5	25.8	27.0	32.0	31.0	27.0	30.2	–
UT29	11.5	11.5	12.8	10.9	12.8	8.7	12.0	10.4	13.1	–	11.0	11.3
UT34	15.0	16.0	19.0	17.3	16.0	14.2	16.0	15.0	16.7	15.0	16.7	58.0
UT38[b]	–	–	28.0	–	31.0	28.0	22.0	33.0	26.5	25.0	–	–
UT42	37.7	41.5	52.3	40.2	40.0	–	–	–	31.0	33.0	33.0	78.0
UT43	34.7	37.3	33.4	37.0	37.7	21.5	57.5	30.0	44.0	36.0	32.0	–
UT44	9.7	10.0	11.4	7.7	8.5	10.0	28.0	27.0	40.0	13.5	11.8	24.0
UT45	–	125.0	105.0	119.0	130.0	44.3	44.5	83.0	73.0	–	135.0	–
UT47	169.0	173.0	186.0	122.0	131.0	–	–	–	–	143.0	153.0	–
UT48	52.7	62.5	53.6	41.0	70.0	56.0	182.0	155.0	63.0	–	57.0	67.7
UT51	94.0	127.0	105.0	117.0	175.0	203.0	200.0	211.0	112.0	113.0	127.0	–
					Bicarbonate—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	329	304	317	316	292	292	202	241	275	279	304	453
UT13	–	–	262	247	293	191	–	270	208	–	–	–
UT18	383	333	353	372	326	317	342	277	336	375	359	–
UT29	189	192	211	192	187	172	191	220	199	–	194	192
UT34	289	300	313	306	287	285	243	186	254	314	297	212
UT38[b]	–	–	274	282	281	272	285	294	265	277	474	–
UT42	276	256	249	282	286	–	–	–	271	278	276	–
UT43	287	285	287	291	292	226	246	208	361	310	307	–
UT44	233	232	220	198	167	200	–	314	217	260	248	158
UT45	–	558	509	437	455	430	295	303	358	–	520	–
UT47	567	456	545	410	448	–	–	–	–	525	525	–
UT48	290	310	312	309	315	324	380	462	294	–	301	296
UT51	477	483	465	464	540	561	416	482	451	520	423	–
					Chloride—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	29.3	26.7	19.0	15.9	19.0	22.0	17.0	31.0	23.0	22.3	23.5	25.0
UT13	–	–	12.9	12.5	10.0	7.7	–	15.0	17.0	–	–	–
UT18	46.0	37.0	39.3	33.3	32.0	30.4	32.5	47.7	29.0	38.0	41.2	43.5
UT29	18.0	24.0	14.5	10.5	10.2	12.0	12.3	16.6	14.7	21.3	20.4	15.4
UT34	27.8	23.0	26.2	19.7	20.0	23.2	19.0	30.0	20.7	27.3	28.3	26.7
UT38[b]	–	–	29.0	–	29.0	33.8	–	37.0	32.0	–	42.0	–
UT42	49.3	49.0	44.7	38.2	36.0	–	–	63.0	40.0	40.0	42.0	–
UT43	52.0	48.3	35.6	43.8	44.7	24.5	48.5	70.0	53.0	57.3	60.0	80.0
UT44	19.3	17.7	9.4	5.0	10.5	15.2	–	26.0	30.5	11.0	17.5	31.0
UT45	138.0	103.0	100.0	52.2	102.0	36.0	26.0	65.3	50.0	87.5	109.0	125.0
UT47	126.0	129.0	127.0	118.0	95.0	–	–	–	–	105.0	115.0	–
UT48	71.7	70.0	50.5	37.6	51.2	42.1	121.0	100.0	46.4	87.0	62.5	66.2
UT51	98.0	103.0	85.1	94.0	167.0	157.0	194.0	215.0	108.0	123.0	121.0	156.0
					Sulfate—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	94.0	103.0	78.2	95.6	99.5	89.5	83.5	93.0	88.0	84.0	87.8	–
UT13	–	–	104.0	72.0	–	54.2	63.0	80.5	98.3	–	–	–
UT18	107.0	98.5	128.0	112.0	110.0	108.0	122.0	110.0	90.3	100.0	102.0	–
UT29	53.0	56.5	55.4	51.0	52.7	41.6	40.5	40.7	43.3	–	52.7	54.3
UT34	53.5	60.8	54.6	57.8	58.7	57.5	68.0	58.0	55.0	61.0	60.8	59.0
UT38[b]	–	–	51.0	–	58.0	52.2	50.0	55.0	49.5	50.0	73.0	–
UT42	288.0	306.0	303.0	262.0	306.0	–	–	–	248.0	267.0	265.0	338.0
UT43	132.0	172.0	156.0	167.0	124.0	97.0	127.0	116.0	163.0	106.0	143.0	–
UT44	42.0	38.3	39.7	25.8	15.0	44.1	146.0	100.0	107.0	32.0	46.8	28.0
UT45	–	235.0	202.0	305.0	124.0	95.0	87.0	144.0	112.0	–	166.0	–
UT47	182.0	163.0	180.0	248.0	144.0	–	–	–	–	161.0	161.0	–
UT48	100.0	85.0	87.0	72.4	105.0	87.5	221.0	199.0	102.0	–	103.0	109.0
UT51	165.0	186.0	150.0	132.0	281.0	343.0	298.0	329.0	170.0	179.0	148.0	–

Table 5a continued.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Temperature—C							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Nitrate—mg/l							
Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UT 9	1.81	1.88	1.78	1.58	1.32	.84	1.13	.40	1.71	1.73	1.73	1.27
UT13	—	—	1.18	.557	1.42	.525	—	6.2	1.80	—	—	—
UT18	2.54	2.23	2.89	2.88	1.90	1.06	1.48	1.65	2.71	1.49	1.40	1.69
UT29	.325	.335	.400	.345	.220	.390	.313	.204	.427	.755	.188	.200
UT34	.91	.71	.93	1.22	1.66	2.16	1.92	1.51	.77	.83	.88	.80
UT38[b]	—	—	1.00	.62	1.58	1.03	11.1	4.4	4.4	—	—	—
UT42	.750	.688	.629	.611	.555	—	—	.605	.36	.68	.79	—
UT43	2.16	1.39	1.41	1.69	2.02	—	.978	1.88	.34	1.28	1.47	1.05
UT44	.900	.748	.760	.512	.442	1.28	—	.48	1.18	.84	.762	.778
UT45	1.64	1.86	2.27	1.46	2.24	1.97	1.54	1.82	2.92	3.60	1.03	1.22
UT47	3.61	2.46	2.41	2.35	2.49	—	—	—	—	1.94	4.06	4.10
UT48	.892	.467	.513	.440	.496	.58	.438	.433	.457	.35	.320	.462
UT51	1.49	1.71	1.38	1.21	.827	.770	.928	.737	.675	.887	1.11	1.20

[a]Quality data largely from the July 1970–July 1973 period, from 1 to 10 observations were available for each parameter each month.
[b]Mill Race averages are for the sampling sites below the Provo STP outfall.
--No data available.

are largely attenuated and assimilated as they pass through ponds, marshlands, and bays bordering the main lake.

Turbidity.— During much of the ice-free season, normally April through November, Utah Lake is turbid, exhibiting a milky gray appearance during calm periods to a gray brown appearance during windy periods. This turbidity contributes more than any other factor to the "polluted" image of the lake. In fact, this turbidity is a natural feature of the lake that has only been slightly aggravated by the activities of man.

The lake bed material is composed mainly of colloidal and fine silt-sized calcite crystals ($CaCO_3$), much of which is precipitated from lake waters. These particles are agitated and kept in suspension by natural wave and water current motions. During the ice-free season moderate waves 0.3 to 0.6 m (1 to 2 ft) high occur almost daily; large waves up to 1.2 m (4 ft) or more are created several times a month by moderate to high winds. These large waves thoroughly churn up the lake bed material, producing a gray brown, polluted appearance that dissipates slowly over several calmer days to the milky gray state. A green hue is added by algae during most of the summer.

Algae growth in the summer and fall increases the pH to high levels, often above 8.3, which causes the chemical conversion of abundant bicarbonate anion (HCO_3^-) to carbonate ($CO_3^=$). The carbonate then combines with the abundant calcium cation (Ca^{++}) to form a fine calcite precipitate ($CaCO_3$). These newly formed calcite crystals are normally very small and tend to remain in suspension. Over time these crystals grow larger and settle to add to the bottom sediments.

Ion balances indicate that about 300mg/l/yr of calcite precipitated during the 1930–79 period. This represents a lake total of 185×10^6 kg/yr (200,000 tons/yr) and an average depth of 0.4 mm/yr (0.016 in/yr) in bottom sediments. Since shallow water sediments migrate to deeper waters over time, the midlake accumulation rate would be somewhat larger. Sediment profiling investigations and mineral composition work summarized by Brimhall and Merritt in the geology paper in this publication estimate the long-term average deeper water sedimentation rate to be about 0.85 mm/yr (0.033 in/yr) and the sediments to be generally 60 to 80 percent calcite, depending on location. Therefore, about 50 percent of the total sediments and 65 percent of the calcite appear to be originating in the lake itself via mineral precipitation. A disproportionate part of the turbidity likely results from this precipitated calcite and other minor precipitates, such as the calcium phosphate compounds ($Ca_x(Po_4)_y$), since these particles are likely smaller than sediments carried into the lake by tributary inflows.

Bacterial Contamination

Coliform bacteria are frequently used as the indicator of sewage pollution and sanitary quality of waters. Some coliform bac-

TABLE 5b. Flowrates in Utah Lake tributaries during the 1979 water year—a typical, near average year (acre-feet).

	1978						1979					
Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
UT 1 & 2	122	20	0	0	0	0	0	170	66	48	13	13	452
UT 4	36	25	24	24	30	33	28	0	0	25	25	24	274
UT 5	80	80	82	82	82	91	86	114	111	51	51	49	959
UT 6	116	120	125	125	110	122	76	76	73	128	128	124	1323
UT 7	65	67	70	70	132	153	51	47	45	197	197	190	1284
UT 8	346	351	365	286	450	1533	485	377	216	204	323	124	5060
UT 9	1195	1442	1286	1534	1406	1664	780	956	1322	503	1242	966	14296
UT 10	3	0	57	118	94	45	23	71	0	33	215	291	950
UT 11	191	148	117	109	95	109	115	244	359	360	180	0	2027
UT 12	105	48	38	38	38	42	61	52	50	105	105	101	783
UT 13	25	45	46	46	82	92	66	156	326	200	54	52	1190
UT 14	86	105	112	113	109	122	132	41	126	145	173	168	1432
UT 15	191	167	169	168	218	250	133	180	223	213	170	164	2246
UT 16	229	120	103	103	62	66	110	73	236	201	123	119	1545
UT 17	375	234	172	137	142	76	100	160	341	228	331	344	2640
UT 18	1677	1303	1615	2190	1370	1286	1119	1011	883	1120	1941	1122	16637
UT 20	2142	2333	2750	2297	2074	2385	2273	2426	2085	1724	1852	2118	26459
UT 23	1	25	31	31	7	6	5	2	2	1	1	1	113
UT 25	23	63	74	74	38	38	30	33	144	105	24	23	669
UT 26	508	475	477	482	447	492	487	546	528	571	586	565	6164
UT 27	1079	1164	1278	1477	1633	1363	1179	1023	951	980	1022	1051	14200
UT 28	0	103	123	123	131	148	73	40	89	103	123	119	1175
UT 29	10340	14730	16940	17250	15430	17320	17700	6160	2360	963	2570	2530	124293
UT 31	148	160	169	169	186	210	98	92	136	108	48	46	1570
UT 32	62	109	123	123	47	46	57	119	50	49	44	42	871
UT 33	18	18	18	18	17	18	28	37	36	42	92	89	481
UT 34	402	258	317	317	317	351	249	178	653	695	591	813	5141
UT 35	154	49	31	31	7	6	1	280	42	93	264	256	1214
UT 36	18	86	103	103	81	87	67	256	115	124	156	151	1352
UT 37	62	55	57	57	65	73	71	94	91	256	280	271	1432
UT 38	499	642	999	1457	679	1115	1286	960	449	534	641	539	4800
UT 39	1342	1240	1207	1180	1160	1294	1206	1446	1496	1979	1874	1832	17256
UT 41	403	349	343	282	119	157	160	134	397	366	513	605	3828
UT 42	1210	875	1352	1356	1314	1655	1437	1768	1891	1304	1535	1699	17394
UT 43	442	723	870	650	577	663	508	327	418	110	612	584	6484
UT 44	1483	2518	3066	2731	2337	1230	9668	13091	14227	2632	0	0	52983
UT 45	201	294	349	322	348	378	270	223	105	63	20	190	2763
UT 46	135	97	133	163	246	181	141	248	243	213	318	178	2296
UT 47	945	1042	1605	2102	1527	866	418	185	46	6	263	49	9054
UT 48	2300	5040	6320	7940	6440	8770	15340	10360	792	181	334	561	54378
UT 48a	31	42	46	46	79	92	55	36	100	94	62	60	743
UT 49	15	15	15	15	78	92	41	15	15	60	63	61	485
UT 50	106	102	143	110	579	238	115	323	400	284	150	313	2863
UT 51	1530	2098	2099	2519	2893	4582	2557	1292	390	370	1036	639	22005
UT 52	54	187	188	336	2122	1518	612	303	147	0	0	0	5467
TOTAL	30,495	39,167	45,607	48,904	45,398	51,058	59,497	45,725	32,775	17,826	20,345	19,234	446,031

[a]Tributaries UT 3, UT 19, UT 21, UT 22, and UT 40 had no flow; UT 40 is being diverted into UT 41.
One acre-foot equals 1233.5 m^3

teria are always found in the lake. The highest counts usually occur near municipal sewage plant discharges and main tributaries. Headman, Ferguson, and Corollo (1949), in a study conducted prior to the construction of any sewage treatment facilities in the area—when considerable raw sewage was discharged—found considerable bacterial pollution near raw sewage discharges along the east shore, as would be expected. However, they also noted the low bacterial levels farther out in the lake. Fuhriman et al. (1975) reported considerably lower bacterial counts in these near-shore areas (presumably a reduction resulting from construction of sewage treatment facilities) with decreases farther out in the lake. Recent samples along the east shore only occasionally exceed the generally accepted swimming water limit of 1000 total coliform per 100 ml. Higher levels normally occur at the mouths of tributaries, which are contaminated in various ways. Pollution from recreation itself may cause high coliform counts in heavy-use areas, such as boat launches and popular fishing areas. Coliform counts away from the shoreline and embayment areas seldom exceeded 100 MPN/100 ml and are usually much lower.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the readily degradable organic matter; it is defined as the oxygen required for microbes to "stabilize" the organic matter present. Utah ambient water quality standards for recreation and aesthetics (class 2 waters) call for a BOD value of less than 5 mg/l. This standard is intended to protect against gross pollution and to avoid low oxygen levels from degradation of organic material. Culinary supply is an unlikely beneficial use of Utah Lake waters because of high TDS and turbidity.

Most BOD data for Utah lake have been taken since 1970. The main lake experiences average summer BOD values of 2 to 4 mg/l, Goshen Bay somewhat higher values at 3 to 6 mg/l, and Provo Bay considerably higher values at 5 to 20 mg/l. Table 6 gives data collected during 1975 by Merritt et al. (Mountainland Association of Governments, 1976). As can be seen in Table 6, some violations of the class 2 BOD standard occur in the lake. In the main lake, these BOD violations result mainly from dead in situ biomass, mainly algae. BOD values are highest with algae dieoff in the fall when high oxygenation from wave-induced mixing largely precludes serious oxygen depletion, as is the case during all the ice-free season. Only a few oxygen and BOD tests have been run on samples from under the ice, and some low oxygen problems exist where the water is less than 1 m deep. They are not pervasive since summer algae have largely died and decomposed before ice cover and fall storms fully oxygenate the lake.

Goshen Bay is much shallower, and wave action and turbidity are generally less than in the main lake. Large expanses of emergent aquatic plants and attached and floating algae are found in the bay, particularly in the shallows. As this organic debris decomposes in the winter, localized low oxygen or anoxic pockets develop under the winter ice but usually are not widespread. BOD loadings from Goshen Bay tributaries are negligible; hence, this is an uncontrollable problem unless in-lake measures are taken to control the growth of the aquatic plants. It is likely that Goshen Bay has been essentially this way for thousands of years.

Provo Bay and several similar, but smaller, bays along the east side of the lake periodically carry high BOD values. These values would generally be higher than those of the main lake, even in the absence of man's activities, as a result of the periodically high BOD loads carried by inflowing tributaries and the high biological productivity in these marsh and pond areas. Thus, even in precolonization times, periodic anoxic conditions occurred in these waters. Until the construction of secondary treatment plants in the 1950s most of the sewage generated in Utah Valley drained into Utah Lake untreated.

TABLE 6. Typical BOD values in Utah Lake (5 day, 20 C values in mg/l).

				Averages[a]	
Station[b]	Number of samples	Minimum	Maximum	With September sample	Without September sample
UL11	4	1.6	6.2	2.9	1.8
UL13	4	<1	8.3	3.6	2.0
UL15	4	1.2	11.5	4.5	2.2
GB 2	5	2.0	20.0	6.6	3.3
PB 2	4	7.1	22.1	12.4	9.2
PB11	4	3.6	12.4	6.4	4.4

[a]Samples taken in July, August, September, and November 1975. Those taken 13 September 1975 were generally from two to four times higher in BOD than for other months, probably due to a heavy algae dieoff.
[b]See Figure 2 for station location.

TABLE 7. Average water quality values for selected locations in Utah Lake.[a]

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Temperature—C						
UL11	11.7	9.9	16.9	22.5	23.8	–	18.7	–	4.9	–
UL13	11.0	10.7	19.8	24.5	24.0	18.9	19.0	9.4	5.0	–
UL15	–	10.8	12.1	24.5	24.3	–	18.7	–	4.6	–
GB 2	–	11.5	13.8	22.2	24.8	21.2	18.4	–	4.5	–
PB11	3.5	12.0	–	25.4	22.1	23.3	17.6	9.4	4.0	2.0
PB 2	4.0	10.2	12.2	14.6	27.0	23.8	17.4	14.5	6.1	–
				Total dissolved solids—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	794	955	894	923	913	913	922	918	893	856
UL13	880	887	854	924	934	915	889	943	891	938
UL15	1073	840	964	969	925	935	925	925	937	941
GB 2[b]	–	965	–	–	948	–	1145	–	890	–
GB 2[c]	–	–	–	2260	2009	2269	–	–	–	–
PB11	751	762	808	–	906	870	898	890	872	835
PB 2	586	532	–	584	529	525	563	575	627	–
				Calcium—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	49	53	58	59	54	46	40	49	51	48
UL13	50	44	58	58	51	46	41	43	42	50
UL15	50	50	62	59	51	48	41	40	44	49
GB 2	–	56	–	–	58	45	42	–	49	–
PB11	–	54	68	–	55	45	40	49	49	–
PB 2	–	63	90	–	56	96	39	96	83	–
				Magnesium—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	52	51	54	53	54	55	59	58	54	51
UL13	52	49	54	53	54	57	56	58	55	56
UL15	59	48	58	56	57	58	58	58	56	57
GB 2	–	54	–	–	71	64	55	–	57	–
PB11	–	45	54	–	48	58	55	57	58	60
PB 2	–	30	32	–	36	30	43	26	40	–

This raw sewage with a BOD of about 150 mg/l resulted in serious oxygen depletion. Secondary treatment plants discharge a BOD of about 30 mg/l and increase in sewered population increased the total BOD load entering Provo Bay to a point where ambient BOD concentrations are periodically as high as 20 mg/l, or more. Most significantly impacted have been the eastern reaches of Provo Bay, which receives urban runoff and treated sewage discharges from Provo and Springville (1980 population of about 85,000 people), and Powell Slough, which receives the treated sewage discharge from Orem (1980 population of about 50,000 people). These discharges compound the natural oxygen depletion problem mentioned above and extend the total area affected; however, it is debatable whether any significant increase in overall environmental degradation and damage results from the marginal oxygen depletion caused by these treated wastewater discharges.

The State of Utah is striving to achieve a reduction in BOD to 15 mg/l in all wastewater effluents by July 1983. At the present time only Provo is meeting this requirement—through its enlarged and upgraded sewage treatment facility completed in 1978. Although achievement of this requirement will reduce the ambient BOD somewhat, particularly in the receiving streams, significant long-term improvement in the aquatic habitat of these bays is doubtful. BOD from decaying vegetation, including algae, is likely dominant during the periods when the most serious oxygen depletion occurs, namely in the late summer and under the winter ice.

Total dissolved salts.— Total dissolved solids (TDS), which range from 700 to 1000

Table 7 continued.

Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Sodium—mg/l						
Ul11	115	144	142	141	143	148	160	150	147	140
UL13	160	143	152	144	153	153	159	170	160	168
UL15	190	133	156	168	153	157	170	164	160	162
GB 2[b]	—	170	—	—	180	—	247	—	160	—
PB11	—	130	145	—	140	175	172	160	146	—
PB 2	—	60	69	—	81	33	124	31	54	—
				Bicarbonate—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	225	246	248	249	228	213	194	212	224	219
UL13	239	250	269	248	226	209	193	195	219	220
UL15	242	248	266	254	230	215	247	204	231	229
GB 2	—	267	—	—	207	196	168	—	256	—
PB11	—	224	214	—	201	186	177	207	222	226
PB 2	—	226	245	—	140	251	110	252	273	—
				Chloride—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	165	176	178	197	197	206	209	206	195	185
UL13	—	190	194	196	201	213	213	228	212	218
UL15	260	179	198	214	245	218	226	223	225	220
GB 2[b]	—	222	—	—	226	260	272	—	232	—
PB11	—	157	173	—	176	—	254	273	177	185
PB 2	—	73	49	—	88	88	76	32	62	—
				Sulfate—mg/l						
Station	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UL11	184	202	206	222	226	240	248	245	220	210
UL13	189	198	210	220	229	243	242	254	237	231
UL15	246	208	213	225	238	258	249	251	239	227
GB 2[b]	—	213	—	—	230	296	233	—	229	—
PB11	—	157	205	—	202	248	250	242	216	219
PB 2	—	124	121	—	141	120	—	128	146	—

[a]Values are averages of all available data from 1968 through May 1976, except as noted. This was generally a wet period with lake levels somewhat higher than the long-term average. During lower water level periods, there is less mixing between Goshen and Provo Bays and the main lake; hence, Goshen Bay would have higher mineral levels and Provo Bay lower levels.
[b]Based on 1975 and 1976 data.
[c]Based on 1970 data. This shallow area in the south part of Goshen Bay is affected strongly by lake level.

mg/l in Utah Lake during typical inflow years and lake levels, are relatively high as compared to drinking water standards, which recommend a 500 mg/l TDS upper limit. Other fresh waters in the area, including the lake's major tributaries, contain about 250 to 500 mg/l. Irrigation water quality requirements vary, depending on crop type, drainage, soil, etc., but it is an incipient problem at about 1000 mg/l in this case because lands irrigated with these waters in Salt Lake Valley are already alkaline and poorly drained.

TDS in Utah Lake sometimes have rather large spatial and temporal variations. In the past, these variations have not always been properly interpreted. Cameron (1905) incorrectly interpreted an increase in salt content of water samples from the lake in 1904 compared with an 1883 sample as an indication that irrigation in the drainage basin was causing permanent decline in water quality. The error of this interpretation was pointed out by Decker and Maw (1933) and by Viers (1964)—who indicated the fallacy of using a single sample at an unknown location on the lake (as reported by Clarke in 1884) as being representative of the entire lake. Viers (1964) presented data to show that the salt concentration in the lake was not permanently increasing with time. Concentrations do increase in summer months when evaporation is high, and they are always higher in Goshen Bay and lower in Provo Bay than in other parts of the lake. Table 7 shows differences in several parameters, including total dissolved solids, in the lake at

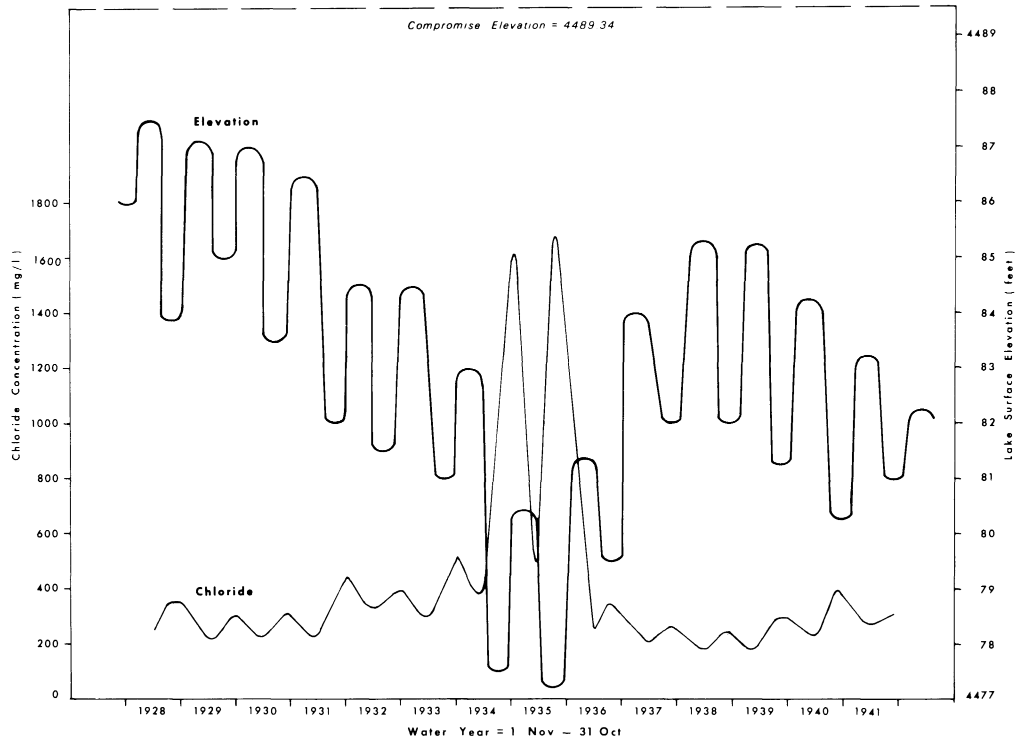

Fig. 3. Utah Lake water elevation and chloride ion concentration, 1928–1941.

TABLE 8. Water and salts percentages to Utah Lake by source—July 1970 to July 1973.

Inflow category	Annual average volume		Percent of total loading to Utah Lake							
	acre-feet	Percent	TDS	Na	Ca	Mg	K	Cl	HCO_3	SO_4
Surface	519,751	82.0	61.3	38.8	77.2	76.8	47.4	37.1	73.8	63.7
Shallow subsurface	86,467	13.6	17.4	27.6	15.3	12.9	22.1	18.1	21.2	20.4
Deep subsurface	27,888	4.4	21.3	33.6	7.5	10.3	30.5	44.8	5.0	15.9
TOTAL	634,106[a]	100.0								

[a]Precipitation is not included since it carries essentially no TDS—see Table 3.

different locations by months. Table 7 values are based on data taken during the 1968 through 1975 period, a relatively wet period with lower TDS concentrations, due to the increased inflow of low TDS surface waters, and high lake levels. During high-level periods, there is more mixing and circulation in the lake proper, as well as with Provo and Goshen Bays, and spatial variations are less pronounced than during lower lake levels.

During a prolonged, several-year dry cycle, lake inflow may drop markedly but evaporation continue, thus causing a large increase in TDS. Figure 3 shows this response for the driest period on record, which occurred during the 1930s. Data were taken from simulations done by the U.S. Bureau of Reclamation (1961). Chloride ion concentration increased from normal levels of about 200 mg/l to a peak of 1700 mg/l during the summers of 1934 and 1935. Since a proportionate increase in other ions likely occurred, TDS values in excess of 4000 mg/l were probably present at that time.

Table 8 gives the relative quantities of salts (TDS) carried by major categories of inflow to Utah Lake. These values were obtained from the LKSIM model discussed earlier. The values for deep subsurface inflow are the most open to future revision, since limited data are available for the mineralized springs. Many of these springs and seeps occur in the lake bed itself and cannot be located and sampled in most cases. Mineralized springs for which some data were available are Saratoga Hot Springs, Bird Island Springs, Lincoln Point Springs, Goshen Bay North Springs, and Goshen Bay South Springs. Since the mineralized springs are the major sources of sodium, potassium, chloride, and sulfate ions—which were needed to obtain a good salt balance in the lake—the five springs given above were selectively increased in flow volume until the "best" salt and water balances were achieved. In other words, it was assumed that the quality of other unidentified mineral springs in the lake could be represented by the quality of those identified. In actual fact, co-mingling of mineral and fresh waters likely occurs prior to emergence into the lake.

Values given in Table 8 indicate the large impact that mineralized inflows have on TDS and ion concentrations in the lake—a much larger impact than previously recognized. For example, mineralized springs provide only 4.4 percent of the water but 21.3 percent of the TDS, 33.6 percent of the sodium, and 44.8 percent of the chloride.

Trophic Condition

Utah Lake is highly eutrophic, meaning that it has a large nutrient loading and experiences very high algal productivity. Procella and Merritt (1976) reported that algal bioassays on Utah Lake waters, using *Selenastrum capricornutum* as the test alga, indicate phosphorus to be the limiting nutrient, although standard chemical tests indicate a relative abundance of phosphorus as well as nitrogen in the water samples. These algal bioassays were run on waters collected at several sites in September and November 1975 and May 1976. They postulated that high hardness and high pH of the lake waters result in precipitation and/or chemical binding of phosphorus, thus rendering it less available to the algae. Nearly all bioassays also exhibited a delayed response to phosphorus and nitrogen additions, indicating that trace metals were not readily available and their release rate from precipitates was a controlling factor in the growth response. This is an expected phenomenon in these high alkalinity and high pH waters, where precipitation of most trace metals with the relatively abundant carbonate ($CO_3^=$) and hydroxide (OH^-) ions would be expected. Overall, algae productivity is likely limited in the lake itself by the high turbidity, although no in situ algal-growth experiments have been run to precisely quantify this factor.

Merritt, Rushforth, and Anderson (1976) reported nutrient loadings to Utah Lake as shown in Table 9. About 95 percent of the total phosphorus load comes from surface tributaries. About 68 percent of this load comes from treated municipal sewage effluents that flow into these tributaries. Somewhat less than 68 percent actually reaches the lake since some phosphorus precipitation, sedimentation, and biological uptake occurs prior to reaching the lake.

The mean annual total phosphorus concentration from all waters flowing into the lake is about 0.20 mg/l, which is an extremely high loading for a "fresh-water" lake with a water retention time of about one and one-half years if based on total inflow and about three years if based on outflow. Evaluations by Merritt et al. (1976) show removal of all phosphorus from sewage effluents would still leave the lake with a "eutrophic" ranking according to results obtained from a commonly used eutrophication model (Larsen and Mercier 1975).

These findings cast considerable doubt on the feasibility of controlling algae production in Utah Lake via nutrient control in tributary waters. It appears that sufficient nutrients are present "naturally," i.e., from uncontrollable sources, to provide an abundance of nutrients to the lake as a whole. It also appears that, due to high alkalinity, pH, and hardness, most of the phosphorus and trace metals are chemically bound in precipitates, and nutrient availability is controlled more by solubility and solubization rates than by the total nutrient loadings to the lake. In addition, as mentioned above, the turbidity is probably the real factor limiting total algal biomass in the lake, not nutrients. Much larger algal biomasses are generally observed in lower turbidity, sheltered areas, thereby qualitatively supporting this proposition.

TABLE 9. Nutrient budget for Utah Lake[a].

Source	Inflow acre-feet/yr	%	Inorganic nitrogen kg/yr	%	Total phosphorus kg/yr	%	Orthophosphorus kg/yr	%
Surface inflow	520,000	72.1	1,745,400	95.7	184,000	95.5	135,000	97.4
Sewage effluents	(26,900	3.7	275,100	15.1	126,000	65.4	105,000	75.7)
Shallow groundwater	86,500	12.0	40,570	2.2	2,780	1.4	2,130	1.5
Deep groundwater	27,900	3.9	5,500	0.3	520	0.3	450	0.3
Precipitation	86,500	12.0	32,000	1.8	5,340	2.8	1,070	0.8
Total inflow	720,900		1,823,470		192,640		138,650	
Surface outflow	353,000	49.0	289,800	15.9	159,000	82.5	54,800	39.5

[a]Flows are averages for July 1970 to July 1973, a period from 10 to 15 percent above the long-term average. Nutrient quantities were based primarily on 1974 and 1975 data. Phosphorus data prior to 1974 seem to be inaccurate.
[b]Sewage effluents discharge into surface tributary waters and their impact is included in the surface inflow values. These effluents are from the following: Lehi, American Fork, Pleasant Grove, Orem, Provo, Springville, Spanish Fork, Salem, and Payson. These plants serve a combined 1975 population of 144,000. The sewered population is projected to increase to 284,900 by 1995 (Mountainland Association of Governments 1976).
1 acre-foot/year = 1233.5 m^3/yr

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