Cyclic water levels in Clear Lake, Riding Mountain National Park, Manitoba

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Abstract: Water levels in Clear Lake have ranged from an estimated mean daily high of 615.940 m in June 1994 to an historical mean daily low of 614.788 m (November 1961). The 115.2 cm range suggests significant variability in water levels over the 39-year period of record. The mean daily water level for the 1960-1998 period is calculated to be 615.275 metres above sea level. The standard deviation for the data is 0.195 m or 19.5 cm.

The 1960-1998 lake elevation records suggest that Clear Lake experiences cyclic high and low water levels. Cyclic water levels in the Clear Lake system are controlled by winter snow accumulation summer rainfall, evaporation losses, run-out discharge, the morphology of the outlet channel and beaver.

Normally, there is a ten-year period between extremely high and extremely low lake levels (e.g. low 1961-1962, high 1969-1971, low 1980-1844, and high 1993-1995). Low water stages are almost always associated with regional drought and appear in the lake stage record approximately every eleven years; 1962, 1973, 1984(?) and perhaps 1998. Extremely low water levels 1962, 1984 have a recurrence interval of approximately 20-25 years.

It appears that extremely high lake stages also occur every 20-25 years and persist over several seasons, approximately five to six years. These periods of extremely high water have been subdivided into three phases. The initial phase involves a two to three year period of high water, which is associated with wetter than normal conditions, and little or no runout down Clear Creek.

Normal or low water stages, which occur prior to the initial high water phase, expose the Clear Creek outlet sill to wave action and ice thrusting. During these times easterly winds build-up a beach crest or sand berm

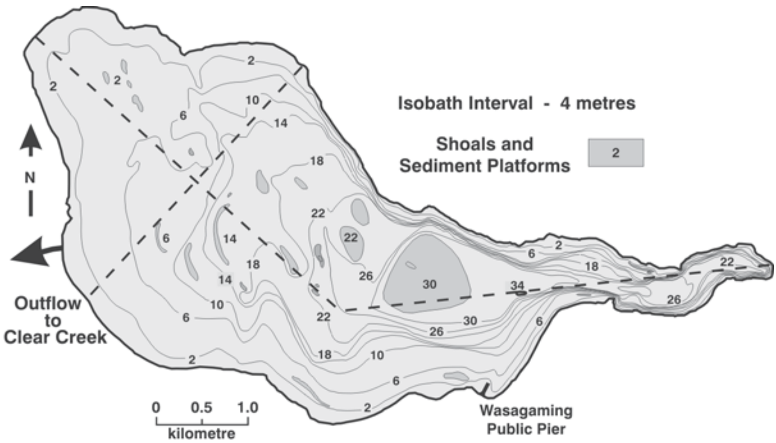
across the outlet. These processes effectively raise the elevation of the outlet sill, inhibiting runout discharges and increasing the storage potential in the lake. Stream discharges equal to or less than 0.8 m^3 s^{-1} support beaver populations. A stair-step profile develops along the low gradient (< 0.002) outlet channel consisting of a series of beaver dams, impoundments and shallow, low flow connecting channels. Runout discharges from Clear Lake are small (< 0.2 m^3 s^{-1}) and may become sub-surface moving through the outlet berm.

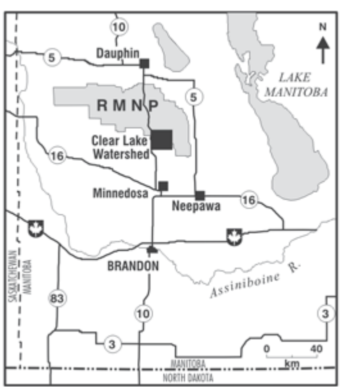
The second (critical) phase in the "extremely high water" years begins when lake levels reach a critical threshold (approximately 615.600 m above sea level). Discharges are forced down Clear Creek, eroding the beach crest (berm) and scouring the channel. During this one to two year period, mean runout discharges generally increase as the channel cross-sectional area increases.

The final (draining) phase in the extremely high water years begins when the outlet channel has achieved maximum cross-sectional area. This phase usually lasts two to three years. Runout discharges peak at values ³ 2.0 m^3 s^{-1} and then fall to values < 1.0 m^3 s^{-1} as lake levels drop. Once runout discharges are < 0.8 m^3 s^{-1} the beaver return to the Clear Creek channel, initiate the development of the low gradient stair-step profile and further restrict outflow discharges.

Introduction

The Clear Lake watershed is centrally located on the Riding Mountain Uplands in southwestern Manitoba (Figure 1). The watershed drains an area of 142.18 km^2 of which over 65 percent is located in Riding Mountain National Park. Clear Lake represents approximately 20.7% of the watershed area (Figure 2). Park managers have recognised the need for data acquisition and scientific study regarding the Hydrologic Water Balance of Clear Lake and the associated watershed. This scientific knowledge is fundamental towards an understanding of the physical, chemical and biological processes, which occur in the watershed. Baseline data will ultimately provide a sound foundation for the development of both short term and long term park management plans for the preservation of the natural state in the Clear Lake watershed.





Clear Lake Statistics

Length	12,095 m
Width	4,524 m
Mean Depth	11.51 m
Maximum Depth	34.20 m
Maximum Fetch	10,095 m
Surface Area	29.37 km^2
Volume	338,075.015 dm^3
Flushing Period	10.72 yrs

Figure 1: *Location of study area and Clear Lake bathymetry.*

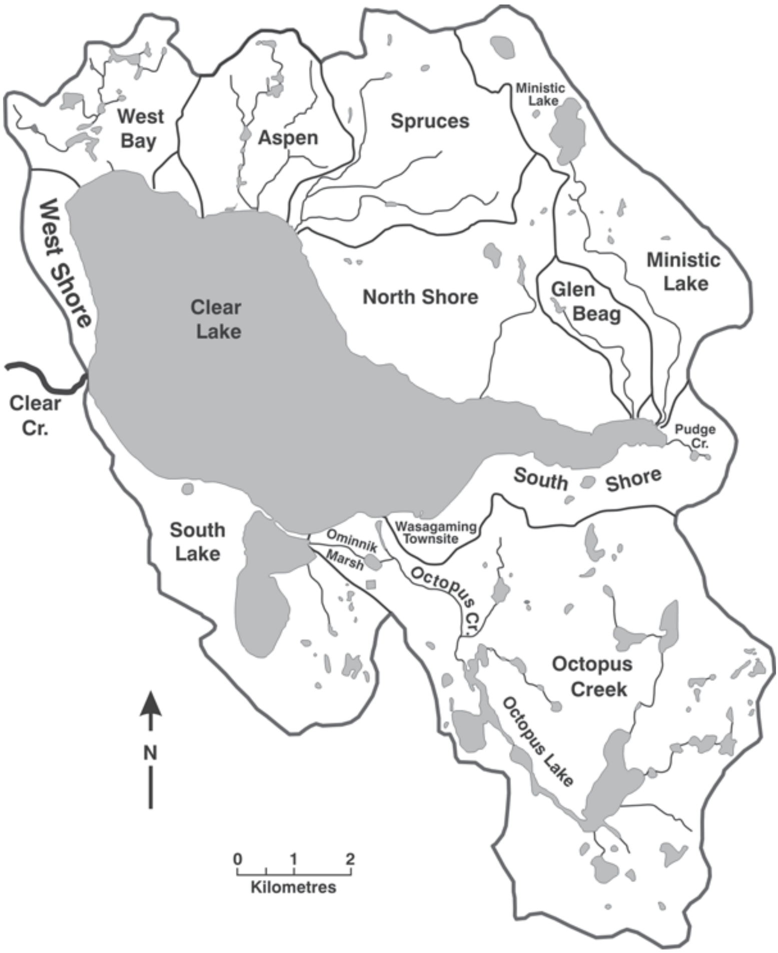


Figure 2: *Sub-basins of the Clear Lake watershed.*

The Components of the Clear Lake Drainage Network

Clear Lake is the most significant storage component in the Clear Lake drainage network (Figure 1). The lake covers an area of 29.37 km^2 (20.7% of the total watershed area) and has a maximum recorded depth of 34.2 m. Clear Lake has a west-east orientation; wider and shallower in the western portion and narrow and deep at the eastern end (Figure 1). The water body is approximately 12,095.0 m in length along a mid-lake line and approximately 4,524.0 m wide. The mean depth is calculated to be 11.51 m. It is estimated that Clear Lake holds approximately 338,075.015 m^3 of stored water.

Normally, Clear Lake is classified as oligotrophic, deep and deficient in plant nutrients (Bazillion and Braun 1992), and considered to be diamictic in that there is a spring and fall turnover. In the summer however, Clear Lake becomes thermally stratified and during these times the lake may be classified as holomictic or completely mixed (Bazillion and Braun 1992). The flushing period, defined as the time required to drain the storage volume of a water body through the outlet, is calculated to be 10.72 years. This number is based on a storage volume of 338,075,015.0 m^3 and a mean daily outlet discharge of 0.1 m^3 s^{-1}. It should be noted that recorded outlet discharges (measured between 1994 - 1998), range from 0.0 m^3 s^{-1} to 2.8 m^3 s^{-1}. The spring melt average discharge is estimated to be 1.0 m^3 s^{-1}. Prior to 1994 however, outlet discharges are believed to have been near 0.0 m^3 s^{-1} as the outlet channel was very shallow, narrow and overgrown with vegetation.

Prevailing winds during the open water period (May - October) are from the southeast (26.6% of the time) and northwest (23.7% of the time). During these periods the maximum fetch is approximately 7,666.0 m. Extreme winds are generally from the southwest (May - July and September) with a maximum fetch of 4,142.0 m. In August the extreme wind events are from the west. When these winds occur the maximum fetch is over 10,095.0 m and this physical combination can generate a small wind set-up in the narrow eastern end of Clear Lake.

Other significant water storage components comprising the Clear Lake drainage network include South Lake, Octopus Lake, and Ominnik Marsh to the south, and Ministic Lake in the northeast (Figure 2).

Surface runoff drains into Clear Lake by way of Octopus Creek, Pudge Creek, Bogey Creek (Ministic Lake Creek), Picnic Creek (Glen Beag Creek) and six intermittent streams located along the north shore of the lake (Figure 2). Three of the most prominent of these intermittent streams have been named Spruces Creek, Aspen Creek, and North Shore Creek for the purpose of identification during this study. Although there is little information at this time, groundwater is also believed to contribute to the storage volume of Clear Lake.

Clear Creek (Wasamin Creek), the outlet stream is located at the western end of Clear Lake (Figures 1 and 2). Water Survey of Canada has not gauged Clear Creek until recently, however, periodic observations suggest that the outlet stream can flow year round and that the mean discharge values are relatively small (0.0 $m^3 s^{-1}$ - 2.0 $m^3 s^{-1}$). Clear creek drains into the Little Saskatchewan River approximately six km upstream of Horod, Manitoba. Until very recently the stream channel was overgrown and the flow impeded by numerous beaver dams and associated storage ponds. It is suspected that groundwater discharge may represent a significant outflow from Clear Lake particularly when the outlet channel has a beaver dam stair-step profile and is overgrown.

Monitoring Programs

From 1960 to 1978 Water Survey of Canada (Environment Canada) monitored the open water lake levels in Clear Lake. A staff gauge, located on the Wasagaming Pier (Figure 1), was read manually and daily lake levels recorded. The lake level monitoring programme ended in October 1978. Monthly mean water level values are illustrated in Figure 3.

With the inception of the Clear Lake Basin Project (1994), Environment Canada, for Parks Canada, again monitored water levels on Clear Lake. The Environment Canada monitoring site, identified as 05MF019, is located on the east side of the Wasagaming Pier (Figure 1). From 1994-1997, a Stevens (A-71)

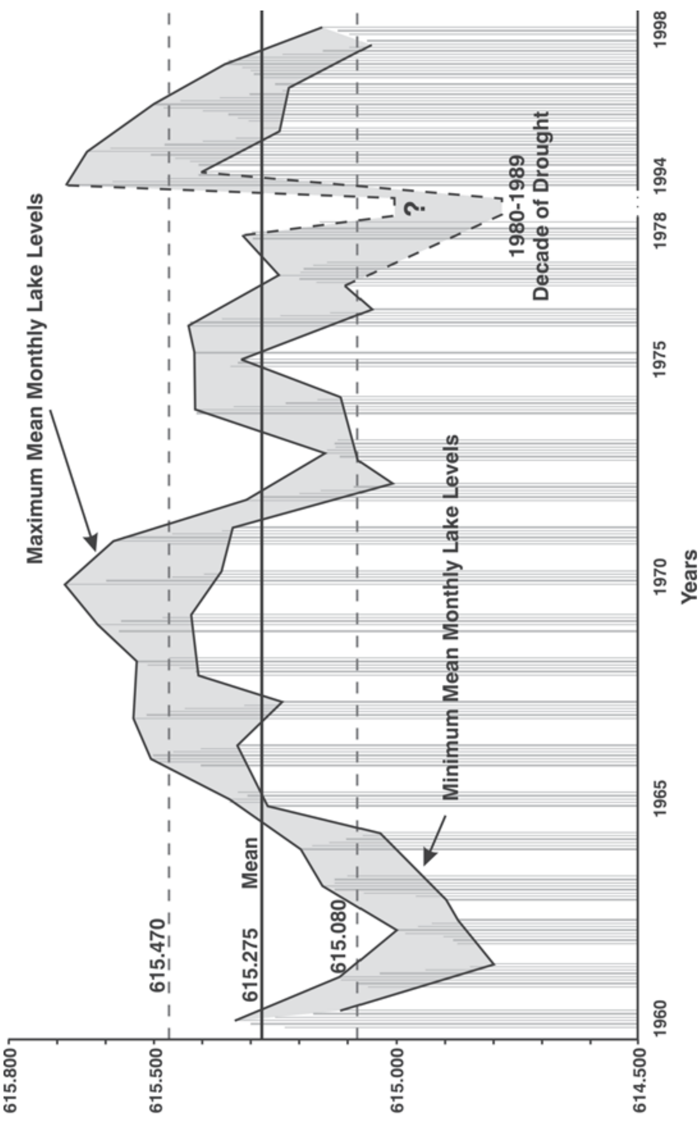


Figure 3: *Lake levels (1960-1978), (1994-1998) Clear Lake.*

Stage Recorder charted the instantaneous fluctuations in lake level and Environment Canada provided calculations of the mean daily lake level. A staff gauge, read by Park officials was also used. On March 24 1997, the stage recorder was automated, converting to an Accubar Pressure Transducer. Water levels, averaged every two minutes, are sent to a VADAS Environment Data Acquisition System, housed in the pump house located on Wasagaming Drive. Environment Canada calculates the mean daily water levels. The Stevens Stage Recorder was removed in spring, 1998. Monthly mean water level values are illustrated in Figure 3.

1960-1978 Lake Levels

The 1960-1978 lake level data set is variable and occasionally incomplete. Water level monitoring on Clear Lake normally occurred during the six-month open water period, May to October inclusively. For three years (1961-1963) however, the monitoring began two months earlier than normal on the first of March. In 1966, 1973 and 1977 water level monitoring began one month earlier than normal on the first of April. These earlier than normal startup times are probably indicative of earlier than normal ice cover break-up dates. Normal break-up occurs in mid May. In 1977 lake level monitoring continued into November, suggesting a late freeze-up. Normal freeze-up occurs in mid November. Some 1960-1977 monthly data are missing: October 1965, June 1969 and May and September 1975. All the 1978 monthly data is missing from the Environment Canada data set.

From a summer peak water level of 615.367 m in July 1960, water levels in Clear Lake declined to the historical mean daily low on November 13, 1961 (614.788 m). The period 1960-1962 is recognized as a time of severe regional drought in southwestern Manitoba (McGinn and Tolton 1989). The Palmer Drought Severity Index (PDSI) (Palmer 1965), a recognized measure of drought, achieved a value of -3.37 in August 1961 (Punak 1990).

The PDSI evaluates moisture conditions at a site in terms of the normal conditions. Normal moisture conditions are assigned a PDSI value of zero. Wetter than normal index values range from

1.0 to 7.0 where a value of 1.0 represents mildly wet conditions and 5.0 is considered extremely wet (Palmer 1965). Drought conditions range from -1.0 to -7.0. A PDSI value of -3.0 is indicative of severe drought (Bryant 1993).

Total accumulated rainfall for the water year (October 1960 - September 1961) was approximately 329.8 mm, about 126.2 mm below normal (Punak 1990). Calculated Potential Evapotranspiration (PE) for the same period was estimated to be 584.6 mm, 31.6 mm above normal. Potential Evaporation, a function of temperature and solar radiation, is an estimate of water demand and is considered to be a measure of evaporative power. The combination of below normal precipitation and higher than normal PE for two water years (October 1959 - September 1961) resulted in declining water levels in Clear Lake and the lowest historical monthly water level (614.798 m) observed (November 1961).

From the 1961 historical low lake level, mean annual water levels rose in Clear Lake throughout the mid sixties (Figure 3). During the 1968-1969 water years (October 1967 - September 1969) the Clear Lake watershed was wetter than normal. Precipitation totals recorded at the Wasagaming climate station exceeded 994.2 mm and the potential for evapotranspiration was lower than normal. PDSI values were positive 23 out of the 24 months (Punak 1990) and for five months in 1969 the PDSI values exceeded 2.0 (moderately wet). Consequently, water levels continued to rise. The highest historical mean daily lake level of 615.723 m and the associated highest historical mean monthly lake level (615.684 m) were observed in June 1970.

Following the historical high water level (June 1970), lake levels decreased as the drought of 1973 approached. A mean monthly value of 614.992 was recorded in November 1972 and lake levels remained below average throughout the 1973 water year (Figure 3). Water levels rose significantly in the spring 1974 and remained near normal throughout the remainder of the decade (Figure 3). The Environment Canada lake level monitoring programme ended in October 1978. The mean daily water level for the 1960-1978 period is calculated to be 615.254 m. The standard deviation for the data is 0.203 m or 20.3 cm.

1994-1998 Lake Levels

Water level monitoring in Clear Lake was re-established on August 1, 1994. The data set is continuous and complete from August 1,1994 to the present and the monthly mean water level values are illustrated in Figure 3.

Mean monthly lake levels from 1994 to 1996 were consistently above the 1960-1978 mean annual lake level of 615.254 m and maximum lake levels for the same period were consistently greater than one standard deviation above the over all mean lake level of 615.274 m above sea level (Figure 3). Consequently, lake stages during these years have been classified as "extremely high water" stages similar to the 1966-1971 years.

Mean annual water levels in Clear Lake have dropped an average of 9.0 cm each year since the peak water levels recorded in August 1994. Mean annual lake levels dropped 9.5 cm in 1995, 6.6 cm in 1996, 11.3 cm in 1997, and an additional 8.8 cm by May 31, 1998. The recorded total decrease in mean annual lake levels from 1994-1998 is 36.2 cm. This value is probably an underestimate since the 1994 spring freshet stages (May and June lake stages) are not included in the calculation of the 1994 mean annual water level.

The mean daily water level for the 1960-1977 and 1994-1998 period has been revised upward by 2.1 cm to 615.275 m. The variance in the data set has decreased slightly and the standard deviation for the data is 0.195 or 19.5 cm). A regression-correlation analysis of the monthly mean lake levels suggests that the August mean lake level of any given year approximates the mean annual lake level for that same year. The correlation coefficient was 0.9816, with $r^2 = 0.9636$ at the 99% confidence level.

Maximum daily water levels in Clear Lake have dropped from an historical high of 615.755 m above sea level, recorded on August 1 1994, to the present (Figure 4). It is assumed that a higher peak lake stage occurred in late May or early June 1994. August mean lake stages are normally 25% - 35% lower than the proceeding spring peak stage. On this basis the peak daily lake level for 1994 could have been approximately 615.940 m, a stage 21.7 cm above the record high observed on June 1, 1970.

The maximum daily lake level for 1995 was recorded on May 19 at 615.658 meters above sea level. This stage was 9.7 cm lower than the August 1, 1994 peak and 12.7 cm (0.127 m) higher than the 1996 maximum daily lake stage of 615.531 m, observed on June 6, 1996. The 1997 peak daily lake level occurred on May 23, 24 and June 2 (615.370 meters above sea level) and this stage was 16.1 cm lower than the 1996 peak. Lake stages recorded on May 28, 1998 indicate an additional decline in peak lake levels to 615.198 m (17.2 cm lower than the June 1997 peak). Maximum annual daily lake levels have dropped 55.7 cm since August 1 1994.

Low water stages parallel the high water trend. The 1994 minimum recorded lake level was observed on November 26 (615.394 m), a stage 11.9 cm above the overall mean annual lake level. By November 15 1995 minimum lake stages had fallen 0.161 m to 615.233 m. Low water stages remained the same in 1996 at 615.232 m (November 11) and declined in 1997 to 615.044 m (November 15), a value 18.8 cm lower than the 1995 and 1996 low water stage. Minimum annual daily lake levels have dropped 34.9 cm since November 26, 1994.

Classification of Lake Stages for Clear Lake, Manitoba

Water levels in Clear Lake have ranged from an estimated historical mean daily high of 615.940 m above sea level in June 1994 to an historical mean daily low of 614.788 m (November 1961). The 115.2 cm range suggests significant variability in water levels over the 39-year period of record. The mean daily water level for the 1960-1977 and 1994-1998 period is calculated to be 615.275 metres above sea level. The standard deviation for the data is 0.195 m or 19.5 cm.

Extremely high water may be defined as a persistent period (two successive months) in which the lake level exceeds the overall mean annual stage by values greater than one standard deviation. Figure 3 illustrates the plot of the annual maximum mean monthly lake stages for Clear Lake from 1960 to1998. This is a discontinuous plot since 15 years (1979-1993) are missing. Most of the 1979-1989 decade is recognized as drought years (McGinn and Cherneski 1992). Consequently, extremely high water is unlikely. The 1990-1991 water years (October 1989 - September 1991) probably represent a period of rising lake levels and the 1992-93 water years (October 1991 - September 1993) a period of "extremely high water" (Rousseau 1998a). Nine years have been identified as "extremely high water" years, 1966-1971 and 1994-1996, inclusively. In each of these years at least two successive mean monthly lake stages are above 615.470 m.

Unusually high water lake stages are defined as a year when the mean monthly lake levels are above the overall mean annual lake stage, and no more than one individual mean monthly value is greater than one standard deviation above the mean. That is all but one of the mean monthly lake stages fall between 615.470 m and 615.274 m. One year, 1975 has been identified as an "unusually high water" year.

Extremely low water lake stages are defined as a two-month period in which lake levels are at least one standard deviation below the overall mean annual lake level. Figure 3 illustrates the annual minimum mean monthly lake stages for Clear Lake from 1960 to 1998. One period of "extremely low water" is identified, the 1961-1964 drought period, which is centred on the very severe drought in 1961-1962.

Unusually low water lake stages are defined as a year when the mean monthly lake levels are below the overall mean annual lake stage, and no more than one individual mean monthly value is greater than one standard deviation below the mean. That is all but one of the mean monthly lake stages fall between 615.080 m and 615.274 m. Two drought years, 1973 and 1977, are associated with unusually low water stages in the Clear Lake watershed.

The historical lake elevation records 1960-1977 and 1994-1998 (Figure 3) suggest that Clear Lake experiences both an annual water level cycle and cyclic high and low lake levels over time. Cyclic water levels in the Clear Lake system are controlled by winter snow accumulation summer rainfall, evaporation losses, runout discharge, the morphology of the outlet channel and beaver.

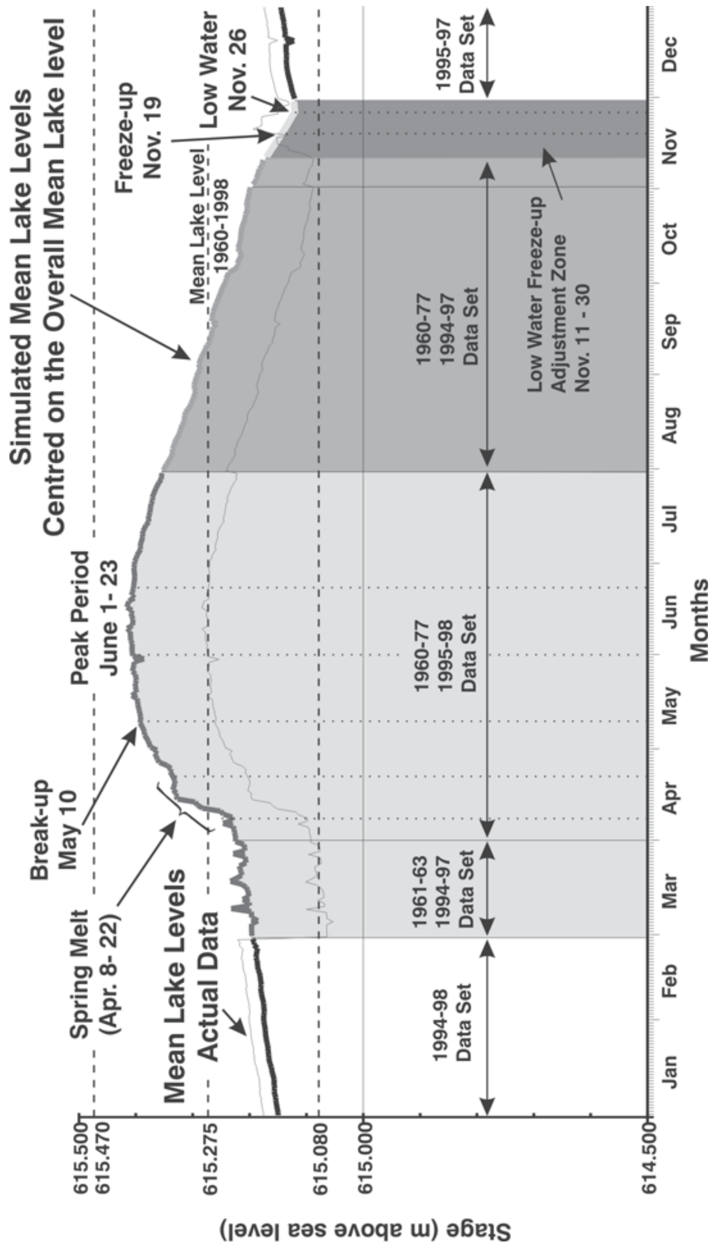


Figure 4: *Simulated lake levels annual cycle, Clear Lake.*

The Annual Cycle

Figure 4 illustrates a simulated normal annual cycle based on the 1960-1977 and the 1994-1998 data set. The discontinuity in the data set leads to several problems in generating an average lake level cycle and is reflected in the calculations of a “Mean Lake Levels Actual Data” plot (Figure 4). January, February and December plots are significantly displaced (a positive displacement) from the March to October plot. Daily mean lake levels calculated for these winter months are based on three or four measurements observed in 1994-1998. Consequently, one daily value recorded during these “extremely high water” years can significantly influence the daily means. By contrast, the April - October daily mean lake level plot is based on 17 to 21 years of data. Since the time frame represents “high” and “low water” years, this segment of the plot is considered to represent the normal annual trend in lake levels. March values are derived from the “low water”1961-1963 period and the “high water” 1994-1996 data. The year 1994 may be associated with the highest lake levels ever recorded and the introduction of these extreme data (August 1994-December 1994) to the calculation of mean lake levels is reflected in a significant positive displacement in the “Mean Lake Levels Actual Data” plot. Likewise, the inclusion of recent November data (a precipitation anomaly in 1997) had a similar impact on the actual data plot (Figure 4).

The simulated plot (Figure 4) is derived by assuming that the March to October plot of mean daily lake levels represents a template of the normal lake level cycle for an average water year. January and February calculations were adjusted (reduced) to the March 1 base. Similarly, the August and early November positive displacements were forced into the continuous plot. The November precipitation anomaly was ignored. The December 31 mean daily lake level was equated to the January 1 value, and December mean daily lake levels were extrapolated backward through late November to the low water date (November 26). Finally, an adjustment linkage joined the extrapolated November data to the composite January - early November graph.

The composite plot of mean daily lake levels was adjusted to the normal mean daily lake level (615.275 m). This was accomplished by placing both the peak lake level and the low water stage equidistant from the long-term mean lake level (Figure 4). Additional information illustrated on Figure 4 includes lake freeze-up and break-up dates, the normal spring melt period, and the time of peak and low water stages.

The annual spring runoff recharges water volumes held in Clear Lake and lake levels rise an average of 18.1 cm. Lake stages normally peak in June, approximately six weeks after the spring melt. During July and August and throughout autumn, lake stages normally decrease due to evaporation loss and runout. The lowest annual lake levels are usually recorded in November. Recent data (1994-1998) support this argument and suggest that lake levels are lowest in late November (a week after freeze up) and begin to rise slightly under the winter ice cover. However, following regional dry periods in the long-term cycle (1960-1962, 1966-1967, 1972-1973, and 1976-1977) low lake stages persist throughout the winter and into early spring. A later than normal spring freshet recharges lake levels and drought-breaking rains can maintain lake stages at levels higher than the early open water months. Consequently, in these years March lake levels are often the lowest in the annual cycle.

The Long Term Wet/Dry Cycle

The historical record 1960-1998 (Figure 3) suggests that there is a ten-year period normally occurring between extremely high and extremely low lake levels (e.g. 1961-1962, 1969-1971, 1980-1844, and 1993-1995). The period 1980-1989 is acknowledged to be a decade of high temperatures and drought (McGinn and Cherneski 1992). During this decade it is reasonable to assume that water levels in Clear Lake remained at or below normal and that an extremely low water lake stage probably occurred in the early 1980’s (1980-1984).

Low water stages, either “extremely low water” or “unusually low water” appear in the lake stage record approximately every eleven years; 1962, 1973, 1984(?) and perhaps 1998. Low water stages in the Clear Lake watershed are almost always associated with regional drought. The only exception occurred during the 1967 regional drought when lake stages were extremely high. Extremely low water levels in Clear Lake have a recurrence interval of approximately 20-25 years. These are always associated with local severe drought.

It appears that extremely high lake stages occur every 20-25 years and persist over several seasons, approximately five to six years. These periods of extremely high water may be subdivided into three phases. The initial phase (Figure 5) involves a two to three year period of extremely high water, which is associated with wetter than normal conditions, and little or no runout down Clear Creek.

Normal or low water stages, which occur prior to the initial high water phase, expose the Clear Creek outlet sill to wave action and ice thrusting. During these times north easterly winds build-up a beach crest or sand berm across the outlet. These processes effectively raise the elevation of the outlet sill, inhibiting runout discharges and increasing the storage potential in the lake. Stream discharges equal to or less than 0.8 $m^3 s^{-1}$ support beaver populations (Rousseau 1998b). As beaver move into the outlet stream, a stair-step profile develops along the outlet channel. This low gradient channel (< 0.002) consists of a series of dams, impoundments and shallow, low flow connecting channels. Runout discharges from Clear Lake are small (< 0.2 $m^3 s^{-1}$) and may become sub-surface moving through the outlet berm. In the autumn of 1993 the Clear Creek outlet channel had a short (30 m) reach, was overgrown with willow and sedges and had dimensions of less than a metre wide and only five cm deep. The channel split into several distributaries and drained into a beaver enhanced wetland. At this time lake levels were well above average and classified as "extremely high water."

The second phase in the "extremely high water" (Figure 5) years begin when lake levels reach a critical threshold (approximately 615.600 m above sea level). Discharges are forced down Clear Creek, eroding the beach crest (sand berm). Observations during the 1993-1996 "extremely high water" period

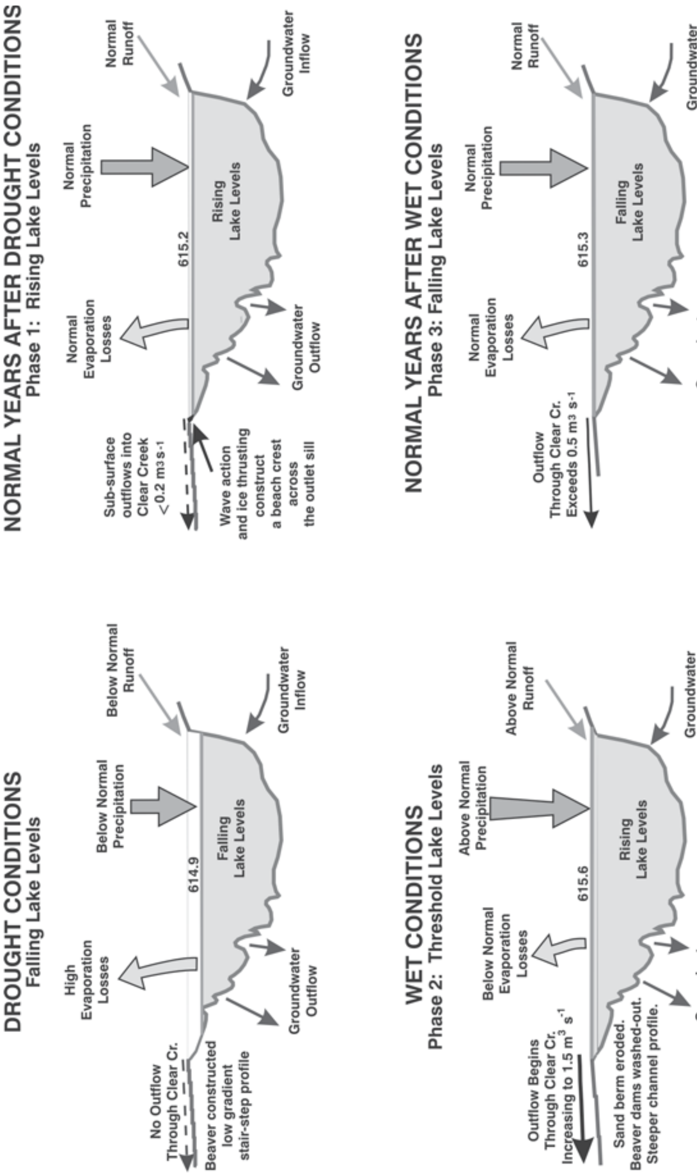


Figure 5: *Cyclic water levels in Clear Lake.*

indicate that two seasons of scour are required to lower the outlet sill and clean out the channel. During this period, mean runout discharges generally increase.

The final (draining) phase in the extremely high water years (Figure 5) begins when the outlet channel has achieved maximum cross-sectional area. This phase usually lasts two to three years. Runout discharges peak at values ^{3} 2.0 $m^3 s^{-1}$ and then fall to values < 1.0 $m^3 s^{-1}$ as lake levels drop. When runout discharges are < 0.8 $m^3 s^{-1}$ the beaver return to the Clear Creek channel, initiate the development of the low gradient stair-step profile and further restrict outflow discharges. Once the beaver become established in the outlet channel, a second threshold lake level (approximately 615.0 m) is required to initiate outlet discharges in excess of 1.2 $m^3 s^{-1}$.

Summary and Conclusions

Water levels in Clear Lake have ranged from an estimated mean daily high of 615.940 m in June 1994 to an historical mean daily low of 614.788 m (November 1961). The 115.2 cm range suggests significant variability in water levels over the 39-year period of record. The mean daily water level for the 1960-1998 period is calculated to be 615.275 metres above sea level. The standard deviation for the data is 0.195 m or 19.5 cm.

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Cyclic water levels in the Clear Lake system are controlled by the lake water balance (winter snow accumulation, summer rainfall, evaporation losses, runout discharge), the morphology of the outlet channel and beaver.

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