A. REGIONAL ASSESSMENT: climate and hydrology 2006

Introduction

Regional water quality patterns found in the lakes of the inhabited areas of King County can be analyzed by comparing the data from all the lakes in water year 2006, in addition to examining data for each lake over time and then comparing to others among the group. Monitoring data on precipitation, water levels, and temperature are compared for all the small lakes measured in 2006 in this section. The discussion of Level II monitoring in other sections covers similar comparisons for Secchi transparency (water clarity), phosphorus, nitrogen, the nitrogen to phosphorus ratios, chlorophyll, alkalinity, and water color. Calculations of the Trophic State Indices (TSI) for each lake will also be compared and discussed.

Precipitation

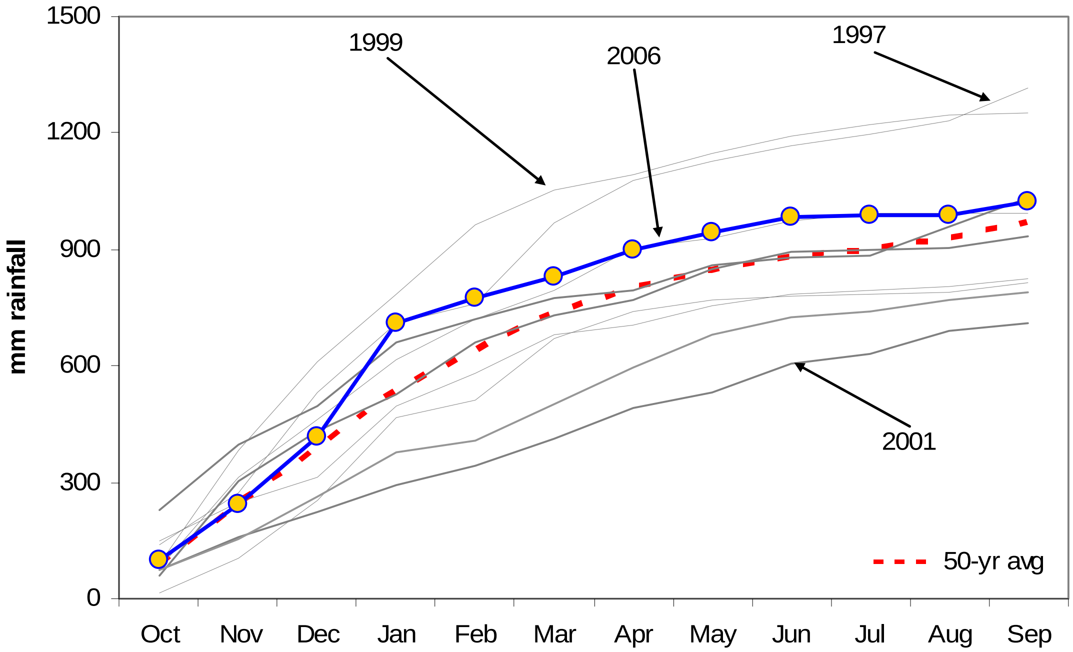
There is a wide range in rainfall received locally in the Puget lowlands through the year because of variation in storm cells, microclimates and land morphology, as well as the pattern of air mass movement between the Olympic and the Cascade Ranges (the "convergence zone"). A variety of other factors, including rain gauge placement, individual adherence to protocols, and personal differences in reading gage levels by volunteer monitors all influence the amount of precipitation recorded for each location. However, consistently measuring precipitation through the years at each lake makes it possible to look at specific changes in lake levels over time relative to the rainfall received in that watershed.

While Level I volunteer monitors collected precipitation data at 27 lakes throughout King County in water year 2006, only 18 lakes had comprehensive rainfall records through the entire period. If the precipitation records for a lake had some gaps, but had data for at least 330 days, estimated values for the missing days were inserted by averaging all available data from the other lake sites in the county for that day. Discussion of the data set is limited to the 18 lakes with the most complete data and the area gage at Seattle-Tacoma International Airport.

Water Year 2006 Precipitation Data

The sum of accumulated rainfall at Seattle-Tacoma International Airport for the 2006 water year (October 2005 – September 2006) totaled 1024 millimeters (mm), which is above the 58-year average of 971 mm (1949 – 2006). This can be visualized by comparing it to the last ten years and to the mean accumulation rate for the last 58 years at the Sea-Tac weather station (Fig. A-1). The accumulation rate through the 2006 water year was equivalent to the 58-year average through the first three months, then jumped in April and remained parallel to the average through the rest of the year. Water years 1997 and 1999 were significantly wetter than average, while 2001 was the driest of the period of 1997 – 2006.

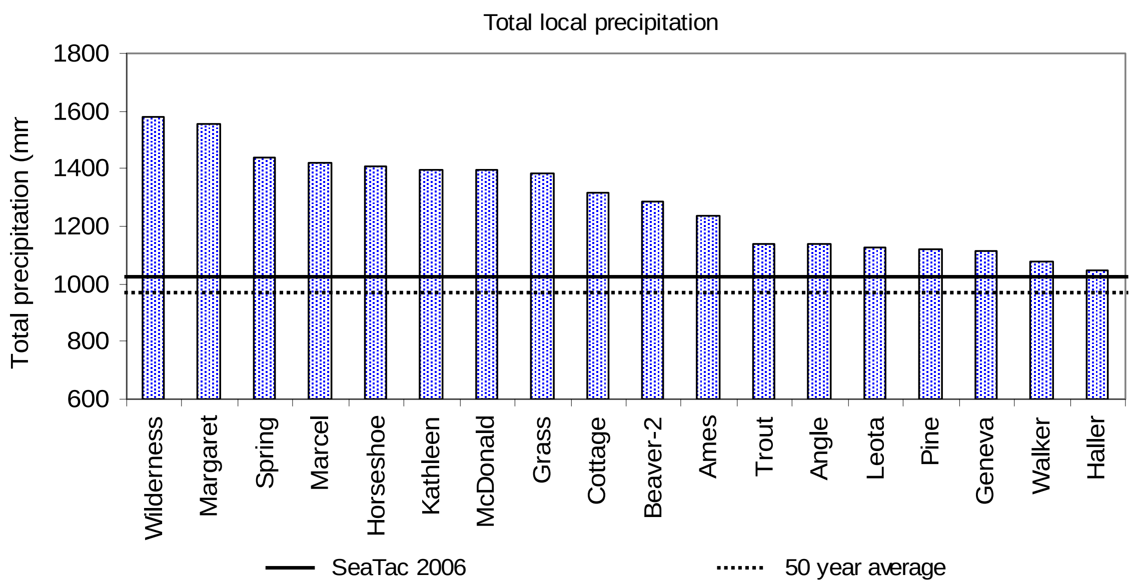
Figure A-1. Cumulative precipitation totals by water year (October – September) for the last decade at SeaTac weather station. The dotted line represents the average accumulation between 1949 and 2006.



Annual precipitation totals for water year 2006 for the 18 lake sites when compared to that for Sea-Tac and the 50-yr average (Fig. A-2) show that almost all sites recorded greater precipitation than the airport gage site (solid line across chart).

The differences between the various sites illustrate the influence that location has on both daily and annual precipitation values, as well as possible differences between volunteers and the individual gages. Since many of the small lakes are located in the middle of the county to the east of the airport location or in the south county, this suggests that there is a consistency found in the pattern and that Sea-Tac data might well be regarded as a minimum for rainfall in the area. Lake stations located to the north or south of the SeaTac weather station include Haller, Trout, Geneva, and Angle, with Angle situated quite close to the airport. It is interesting that Walker Lake, which is nestled on the west slope of one of the foothills near Enumclaw, had records more similar to the lakes near Puget Sound. No other monitored lakes are close to Walker Lake, but both Horseshoe and Wilderness are to the northwest.

Figure A-2. Annual total precipitation for water year 2006 measured at lake sites across King County.



Lake Level

Fluctuations of water level in lakes are affected both directly and indirectly by area precipitation. Some other major influences include: (1) watershed size (also called the "catchment basin"); (2) land use within the watershed boundaries; (3) vegetation types and coverage; (4) nearby or adjacent wetlands; (5) soil structures and types, as well as specific geology of the area; (6) surface and subterranean hydrology; (7) outlet type or structure, with or without management; and (8) the volume of water the lake holds relative to the size of the watershed that receives the rain. These factors combine to give each lake a pattern of water level change that is unique.

Nonetheless, some common fluctuation patterns can be found among lakes. In general, lakes in urbanized watersheds routinely respond more quickly to precipitation events and have greater fluctuations in water level than lakes in undeveloped watersheds. This is largely due to the increase in impervious surfaces throughout the watershed, as well as the collection and channelization of surface run-off for quick removal from developed properties. Lakes with large watersheds may have a delayed response to precipitation because of the distance that runoff travels before entering the lake. Lakes with large surface areas or volumes relative to the size of the watershed are often less responsive than other lakes because the volume of water from a single storm event is small relative to the volume of water they already contain.

Sometimes other factors become important in water level changes. Beavers building dams on outlet streams can keep lake levels high through the summer, while human destruction of such dams can cause sudden drops in water level and unexpected surges of water downstream. Readjusting heights of weirs on outlet streams for management purposes can also account for unusual patterns in lake levels.

Lake Level Fluctuations 2006

Predictable seasonal fluctuations in lake levels were observed at most of the lakes in 2006 with complete data sets. Water levels were typically at the lowest stand during fall (the end of the water year) and steadily increased during late fall / early winter as precipitation increased Data for individual lakes can be viewed at downloaded at http://www.metrokc.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx.

During the fall and winter, many lakes also showed the greatest fluctuation in daily lake level readings, as storm runoff from watersheds with saturated soils or a high percentage of impervious surfaces quickly flowed to the lakes instead of percolating through soil horizons. This type of runoff pattern caused peaks in water levels to reflect large precipitation events closely, which can be seen in records for individual lakes.

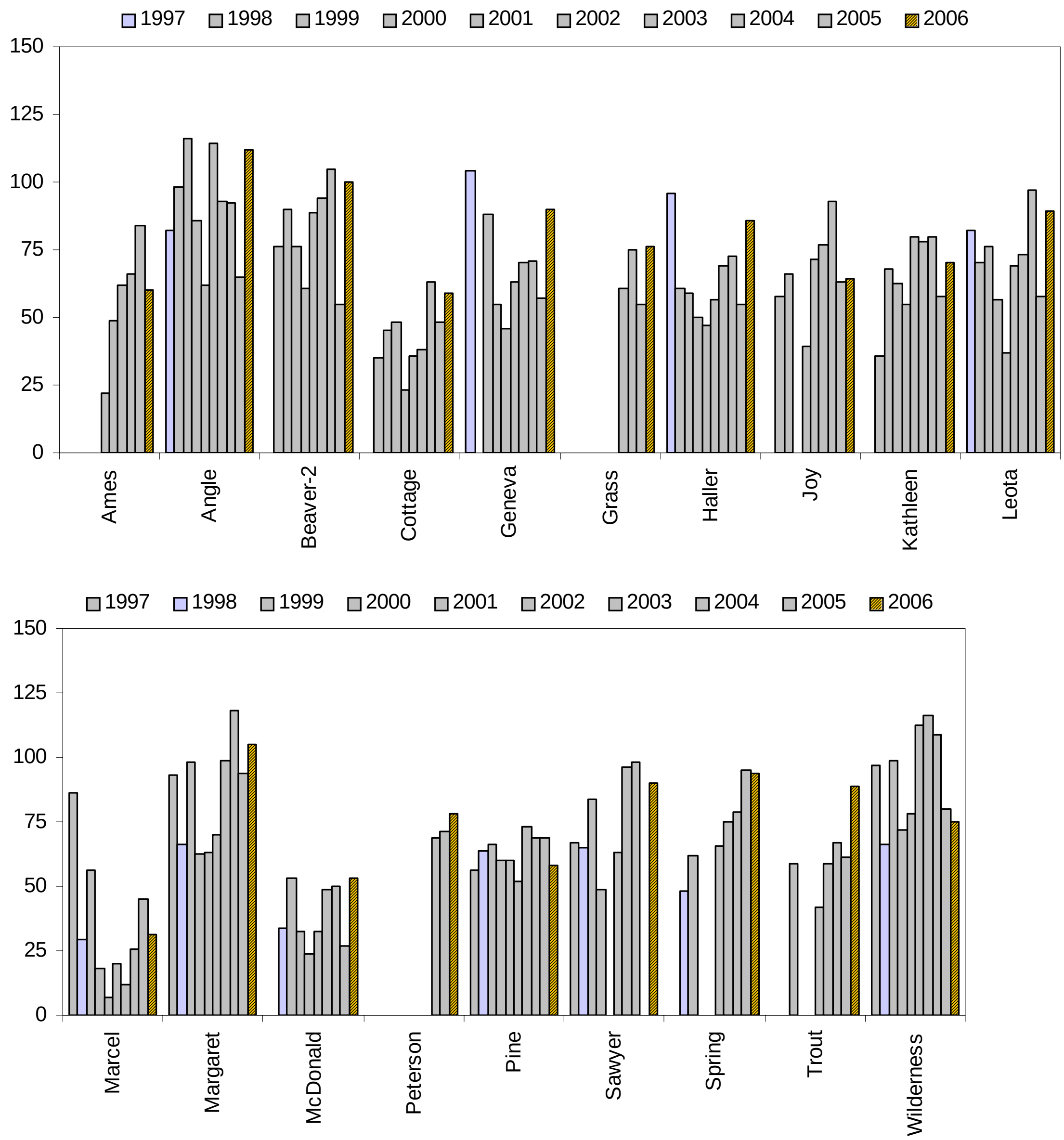
The range in water level is the difference between the maximum and minimum stands over the entire water year. Changes in a particular lake from year to year can be compared as well as comparing records between lakes. Lakes with large fluctuations often show their high sensitivities to winter precipitation and run-off, as well as to evaporative loss through summer. Lakes with small variations in water level probably receive a higher percentage of ground water inputs, which are a steadier source of water through the year than rainfall.

Some lakes are managed at the outlet for desired water levels, but this does not necessarily mean that the annual range will be small. For example, Lake Margaret is kept lower in the winter as a buffer against high levels following rainstorms and is allowed to rise to high levels in the spring in order to store water for domestic use by homeowners in the area. Its fluctuation is controlled for the benefit of the community and does not follow the natural pattern.

Where essentially complete records were available for comparison, lake level ranges in most cases were among the highest fluctuations over the past ten years. Twelve of the recorded annual ranges for the lakes in 2006 were higher than in 2005 and were among the highest ranges found since 1998 (Figure A-3). Lakes in this group included Angle, Beaver-2, Cottage, Geneva, Grass, Haller, Kathleen, Leota, Margaret, Peterson Pond, and Trout. Lakes with approximately equivalent variation in range or slightly less than in 2005 included Ames, Joy, Marcel, Pine, Spring, and Wilderness.

Some lakes are known to have beaver populations living near outlet streams, including Cottage, Peterson Pond, Joy, and Spring. Some management activities have occurred on all the lakes with varying degrees of success, such as trapping, recurring dam deconstruction by citizens, and emplacement of structures called beaver deceivers. Marcel has a population of beavers living upstream from the lake.

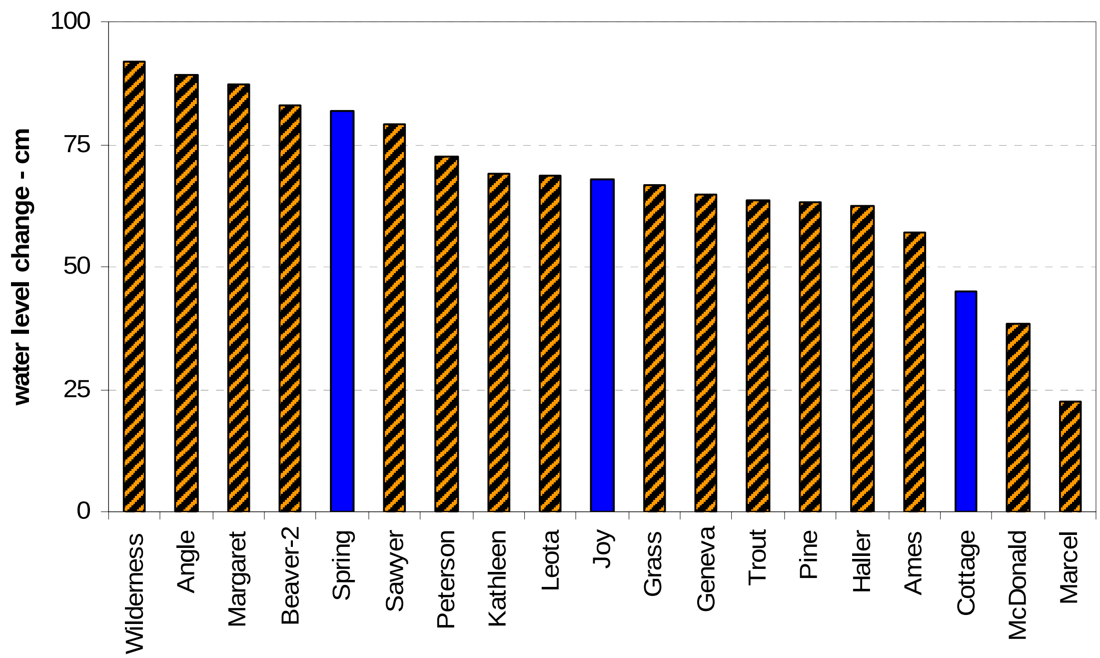
Figure A-3. Annual range of lake level variation between 1997 and 2006 for lakes with essentially complete records of daily lake level measurements.



Some lakes have large changes in water levels every year, while others show much less variation over time. Average values for annual ranges over the past 10 years (Figure A-4) show that some lakes vary by nearly a meter while other lakes have shorelines that move less than a quarter of that amount. Lake Wilderness and Angle Lake, which have the largest average ranges, are both lakes with small watersheds relative to their surface areas, and neither has an inlet stream entering the lake. Lake Margaret, which also has a high annual range, is managed for domestic water-supply and flood control, so water levels do not directly reflect the natural relationship between inputs and outputs. Levels at Lake Marcel are also controlled at the outlet by the community, and there appears to be little variation through the year.

Spring, Cottage, and Joy (all marked in flat blue) are lakes known to have beaver activity at their outlets. All three lakes have had some attempts to control the beaver activities, and so those ranges may reflect some short-term events when beaver dams were taken down by hand.

Figure A-4. Average annual range of water levels between 1997 – 2006, with at least 4 years measured during that period.

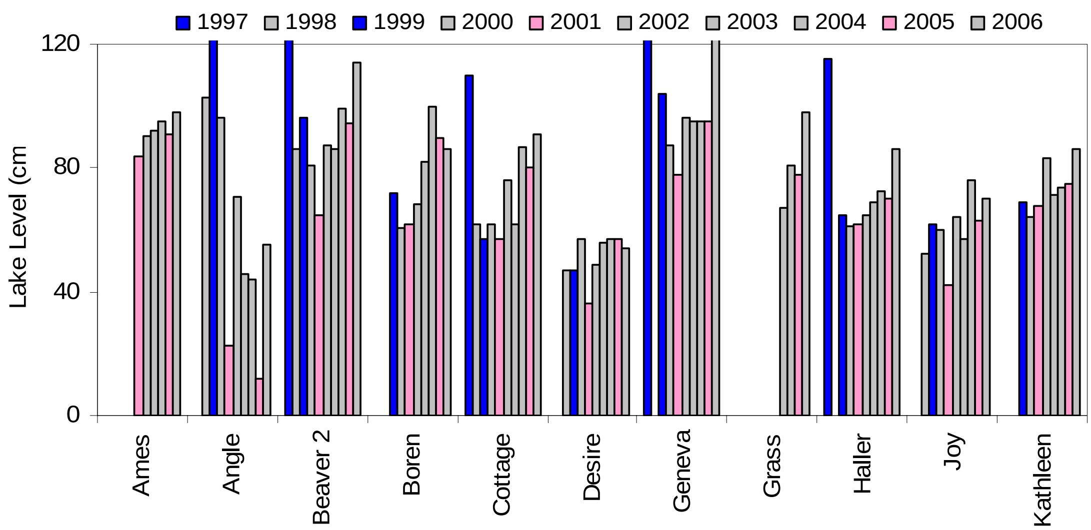


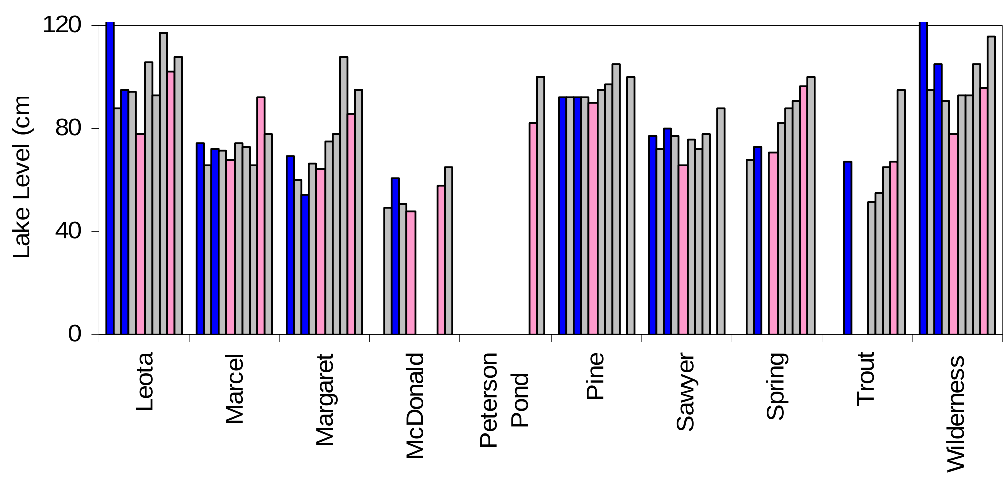
Studying records of annual maximum high water level can indicate whether or not a lake was at its capacity for water storage (at or above the threshold of the outlet) at the end of the wet season each year. It may also be an indicator of whether a lake rose to unusual heights at any point during the wet season. The reported values for high water levels cannot be compared from lake to lake because the measurements for each lake are relative, based on reading the waterline mark on a fixed meter stick. However, an idea can be gained of whether or not the lake was at capacity (water level at or above the threshold for an outlet) by comparing high precipitation years with low ones (Figure A-

5). For this exercise, the best years to contrast are 1997 and 1999 as high precipitation years (the blue bars) with 2001and 2005 as low precipitation years (the pink bars). Other water years (closer to average precipitation) are marked as gray bars.

As an example, Lake Marcel has had a more or less equivalent maximum level for the last five years, suggesting that inputs were balanced by water flowing out rapidly enough to maintain the water at a stable height. Desire, Pine, and Sawyer Lakes also show this pattern. In contrast, Angle, Beaver, Geneva, Haller, Leota, and Wilderness lakes had higher stands in 1997 and 1999 than in average years, suggesting that inputs can overwhelm outlet flow, leading to transitory high water levels. This doesn't take into account the possibility of an extraordinary storm overwhelming the outlet capacity of the a lake.

Figure A-5. Maximum water levels between 1997 and 2006 for selected lakes. Blue bars represent high precipitation water years, while pink bars represent low precipitation water years. Gray bars are years with more typical precipitation.





A number of lakes appear to have winter maxima that appear to be progressively increasing over the last 5 years. These include Ames, Beaver, Haller, Joy, Kathleen, Margaret, Spring, Trout, and Wilderness. There are several possible explanations for this apparent trend, including the idea that larger storms have occurred or that watersheds have continued to develop, leading to greater run-off peaks, but not enough information is available to favor one explanation over another. Beaver activities have increased in recent years, which may increase the height of the lake threshold at the outlet, but this is more likely to affect the lake level year round than to impact maximum lake levels that are well above the threshold height.

Conclusion

Many volunteers recorded high ranges of lake level fluctuations in 2006 than in previous years, and this was matched by higher maximum stands. This suggests that many of the higher ranges could have been due to very high winter stands in response to stormwater input rather than summer rates of evaporation. Continued volunteer observation will be important for determining how changes in natural conditions, management activities, or watershed development all affect individual lake levels. Ongoing monitoring will help lakeside residents, citizens in nearby communities, and city and county officials to understand more thoroughly the trends and relationships of water level fluctuations with precipitation, thus leading to more effective drainage management.

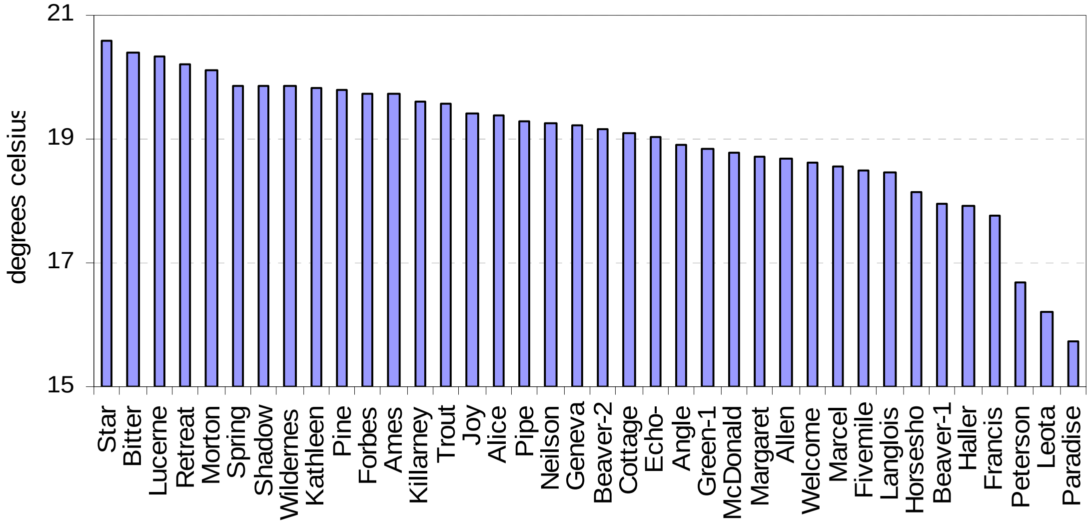
Water temperatures

Lake water temperatures are generally most affected by interactions between solar radiation and water circulation due to wind. Air temperature, ground temperature, water inputs, and relative humidity all play more minor roles.

Lakes that are shallow relative to their surface area often do not develop a warm layer overlying a cool layer in the summer (thermal stratification) because wind energy will keep the water circulating from top to bottom in the water column. Lakes that are deeper relative to their surface area will separate into horizontal thermal layers as the days lengthen and more solar radiation reaches the surface water. Generally this happens in mid-spring in the Puget Lowlands and persists through summer. Shorter daylight hours and persistent winds slowly increase the depth of water circulation in the fall until the whole lake is the same temperature and water mixes freely throughout the water body.

Most of the lakes monitored in the Lake Stewardship Program showed similar degrees of warming at the surface in 2006, although several were somewhat colder than the majority (Figure A-6).

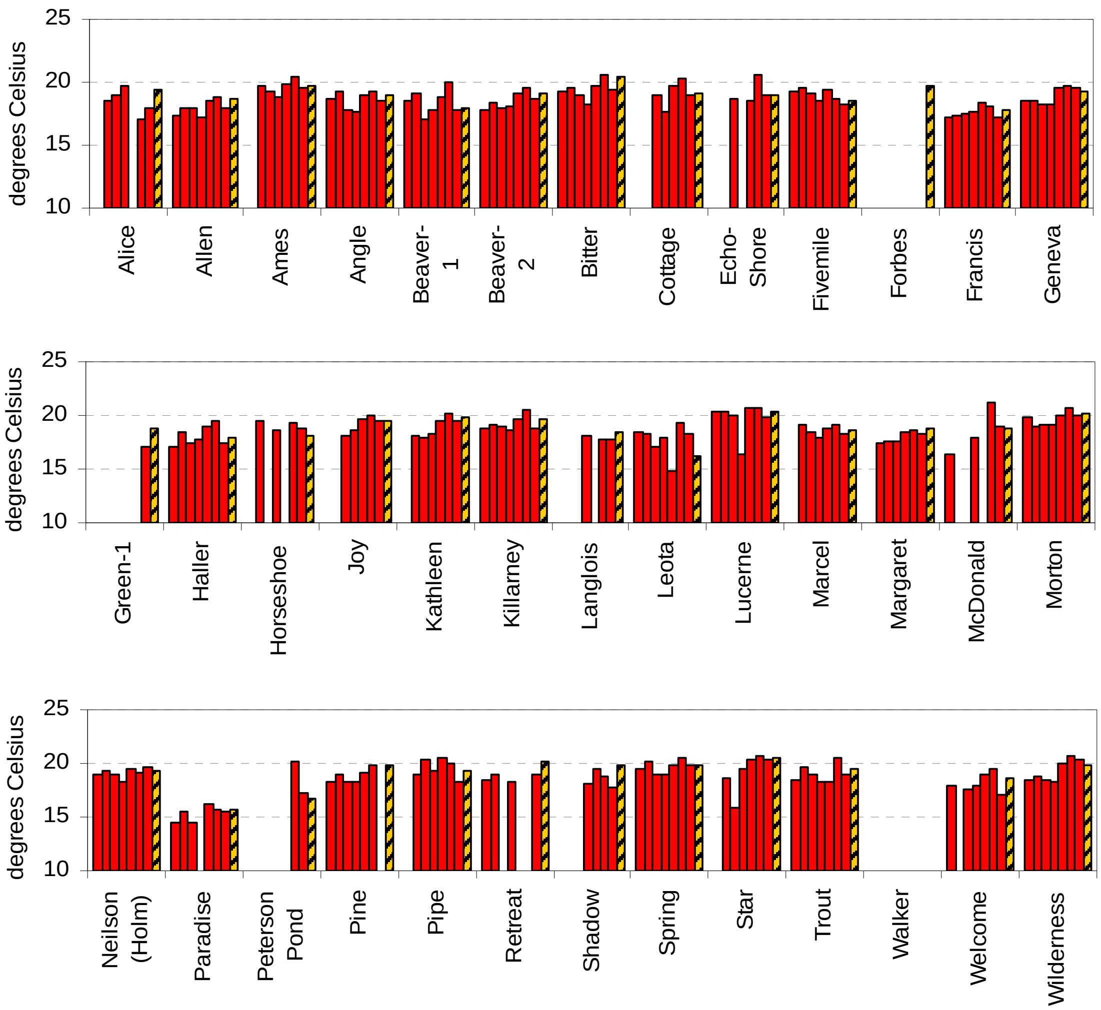
Figure A-6. Average temperature at 1m from May – October in 2006.



There was very little correlation between temperature and lake surface area, depth, or watershed size. There may be some relationship to the amount of water that ground flow contributed, but not enough information is available to evaluate the possibility. The three lakes with the lowest average temperatures, Peterson Pond, Leota, and Paradise, are all fairly small lakes that might have significant ground water inputs throughout the year. The three warmest lakes, Star, Bitter and Lucerne, are all of moderate size and are located in urbanized areas where there may be little inflow of any kind during the summer.

Looking at temperature records over time (Figure A-7) highlights the patterns of temperature across the years of measurement.

Figure A-7. Mean temperature at 1m from May – October for 1999 – 2006.

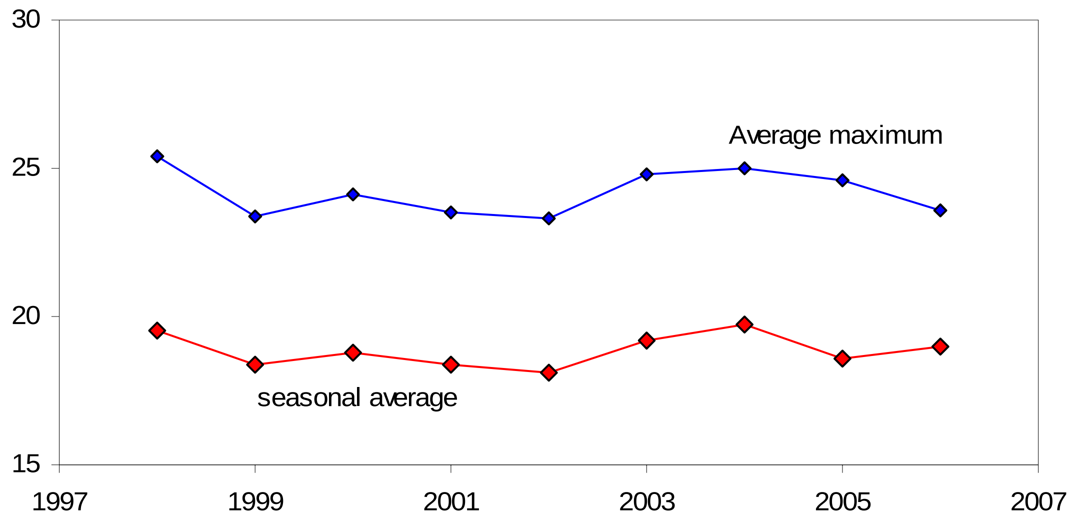


Most lakes have similar average temperatures from year to year, displaying no straight forward trends over the time period. Several lakes, such as Leota, Lucerne, and Star, have much lower temperatures in one year, while others such as Echo-Shoreline, McDonald, and Peterson Pond, have one year much higher than others. Abnormal averages such as these may be due to thermometer liquid separation or calibration problems.
There are several lakes that show possible step-rises in temperature, including Geneva, Kathleen, and Wilderness, while several others may be increasing gradually over time, including Allen, Beaver-2, Joy, Morton, Pine and Star. Lakes which could be decreasing include Fivemile, Horseshoe and Pipe.

Lakes that are consistently among the warmest of those measured each year include Lucerne, Bitter, Morton, and Spring. Among the coolest over time are Allen, Langlois, Leota, and Paradise.

If all of the measured lake temperatures are averaged for each year (Figure A-8), the patterns of the average seasonal temperature and the average of the maximum temperature measured at each lake mirror each other closely. It can be seen that 1998, 2003 and 2004 were warmer years for lake water than the other years measured. However, no overall region trend over time can be found for water temperature.

Figure A-8. Average May-October temperature of all small lakes measured each year, compared with average maximum temperature measured during that period.



The length of the record is probably not yet long enough to look for trends relating to global climate change. However, summer temperatures of lakes may not necessarily reflect some expected climatic changes because warmer winters may not impact summer heat content of the small lakes. If summers also become drier as a part of climate change in this region, then they may also be sunnier, and that would be more likely to produce warmer water temperatures.