Lake Morphology and Morphometry

(Kalff Chapter 7, pp85-93)

A. Lake Morphology (Shape).

Lakes may be described by their shape. Some examples:

Circular: Crater, Chubb (New Quebec Crater)

Subcircular: Many cirque lakes

Lunate: Oxbows

Dendritic: Reservoirs, Landslide lakes

B. Lake Morphometry (Measurement of Shape).

Kalff (2002): ..."Regardless of how lakes are formed, their surface shape, surface area, underwater form, depth and the irregularity of their shoreline have a major impact on turbulence, lake stratification, sedimentation and re-suspension, and the extent of littoral-zone wetlands that determine lake functioning…"

1. The most complete representation of the shape of a lake basin is a *bathymetric map.*

a. Coordinate convention in limnology and oceanography

By convention, the x, y, and z coordinates for lakes and oceans are:

x positive to the east

y positive to the north

z positive down (NOT up).

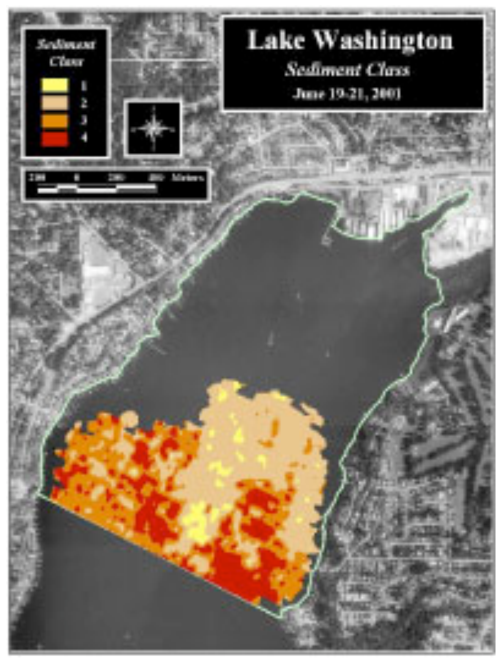
b. Source of data for bathymetry

Historically, depth measurements were obtained by lead-line (slow, tedious, not always accurate). Depth sounders are now readily available and give much more accurate and rapid results. Determining horizontal location is now feasible using electronic and satellite navigation methods. Computer packages are now available that produce a detailed map from depth and gps data collected simultaneously from a boat.

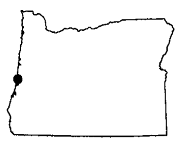
Bathymetric maps represent the shape of a lake by depth contours. The depth interval chosen depends on the detail of the sounding data available and how detailed a map can be printed.

Comment: <u>All published bathymetric maps look plausible</u>, whether or not they are accurate. In particular, if an area of the lake was not sounded, it may contain holes or hills that do not appear in the map. Unless the origin of the map is well known, it is wise to be cautious about accepting a bathymetric map as accurate.

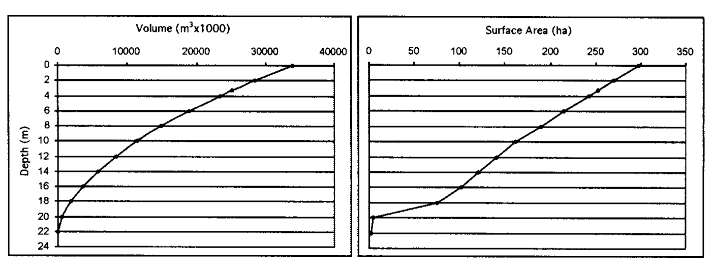
Hydroacoustics can be used for more than depth determination. Applications include sediment type characterization, fish population assessment, aquatic plant mapping, and more!



Bottom classification in Lake Washington

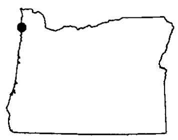


Woahink Lake

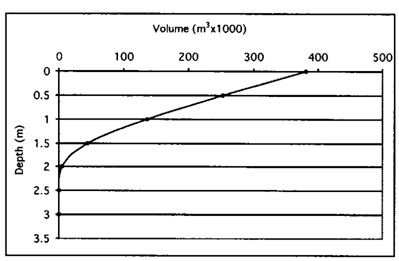


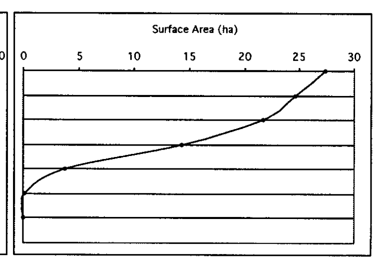
This map is not intended for navigation purposes. Boaters are urged to use caution as hazardous conditioins will change with lake stage.

Map produced by Mark Rosenkranz	January 2002
Portland State University Center for Lakes & Resevoirs	
Data collection date: 09/22/00	



Lake Lytle





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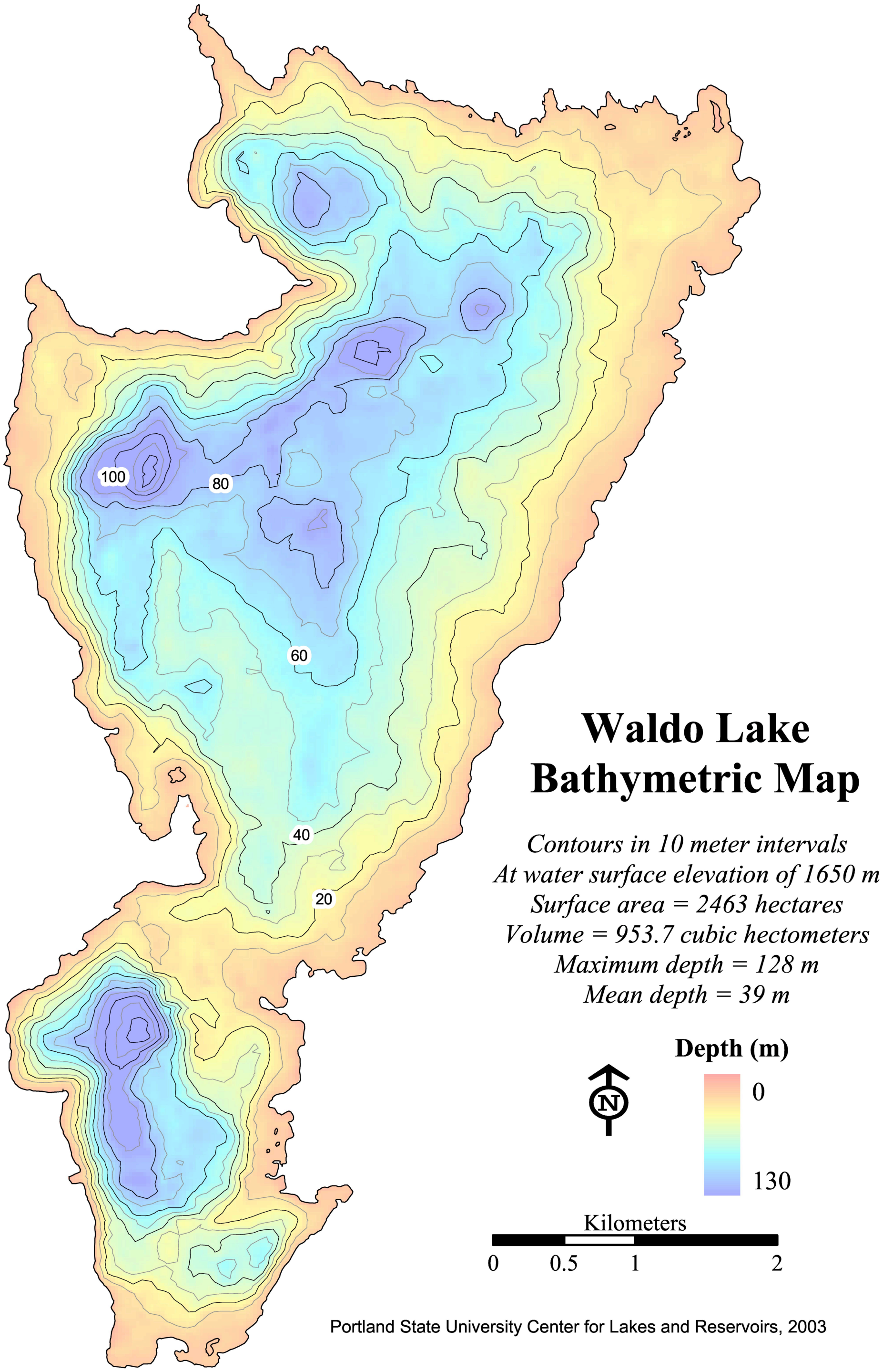
Map produced by Mark Rosenkranz	January 2002
Portland State University Center for Lakes & Reservoirs	
Data collection date: 12/06/01	


100
80
60
40
20
Waldo Lake
Bathymetric Map
Contours in 10 meter intervals
At water surface elevation of 1650 m
Surface area = 2463 hectares
Volume = 953.7 cubic hectometers
Maximum depth = 128 m
Mean depth = 39 m
Depth (m)
0
130
N
Kilometers
0
0.5
1
2
Portland State University Center for Lakes and Reservoirs, 2003

2. Some commonly reported morphometric statistics:

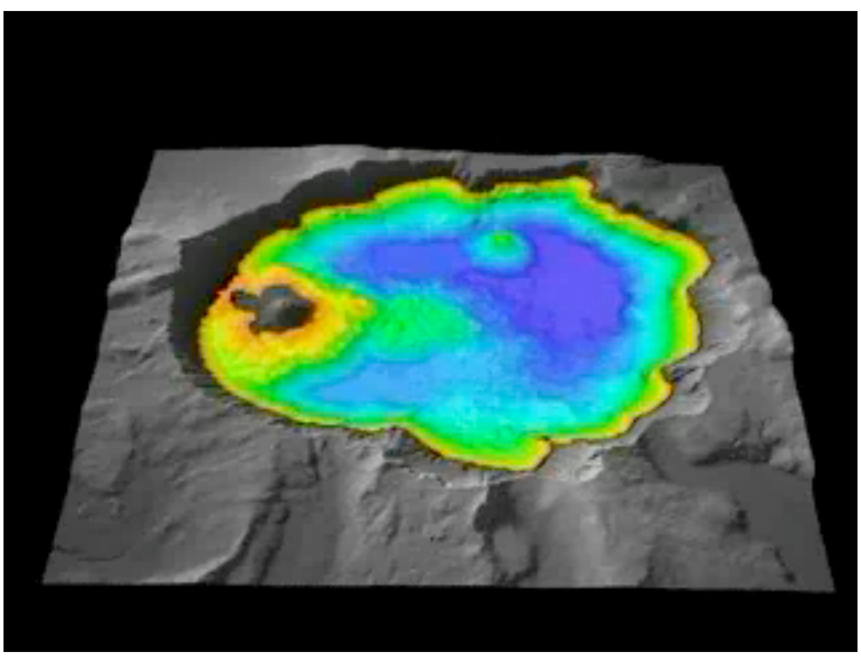
Maximum depth, Z_{max} the maximum depth of the lake.

World's deepest

	Name	Location	Depth
1.	Baikal	Siberia, Russia	5,369 ft (1,637 m)
2.	Tanganyika	Africa (Tanzania, Zaire & Zambia)	4,708 ft (1,435 m)
3.	Caspian Sea	Iran and Russia	3,104 ft (946 m)
4.	Nyasa	Africa (Mozambique, Tanzania & Malawi)	2,316 ft (706 m)
5.	Issyk Kul	Kyrgizstan, Central Asia	2,297 ft (700 m)
6.	Great Slave	Northwest Territories, Canada	2,015 ft (614 m)
7.	**Crater Lake**	**Oregon, U.S.A.**	**1,943 ft (592 m)**
8.	**Lake Tahoe**	**California & Nevada, U.S.A.**	**1,685 ft (514 m)**
9.	Lake Chelan	Washington, U.S.A.	1,419 ft (433 m)
10.	Great Bear	Northwest Territories, Canda	1,356 ft (413 m)
11.	Lake Superior	Canada & U.S.A.	1,333 ft (406 m)
12.	Titicaca	Peru	1,214 ft (370 m)
13.	**Pend Oreille**	**Idaho, U.S.A.**	**1,150 ft (351 m)**

Crater Lake was first explored thoroughly in 1886 by a party from the U.S. Geological Survey who set out to determine the depth of the lake. Their primitive sounding device consisted of a lead pipe attached to piano wire. After lowering it into the water at 168 locations around the lake, they concluded the deepest part of the lake to be 1,996 feet (608 meters). This was only 52 feet (16 meters), or less than 3%, off from the official depth measurement recorded with multibeam sidescan sonar in 2000.

Crater Lake Flyby (http://craterlake.wr.usgs.gov/movies.html)



Length is the shortest distance between the two most distant points on the lake shore.

> "The distance over which the wind can blow and bring about turbulence is referred to as the **fetch**. … Some [estimate fetch using] maximum length…others take length and width into account {(L+W)/2} and yet others use surface area {A or $A^{0.5}$}. Hakanson and Jansson (1983) developed the **dynamic sediment ratio** (**DSR**) as the square root of the area (A) divided by the mean depth (z_{ave}): DSR = $\sqrt{A}/z_{ave}$. to estimate the area of the lake bottom subject to resuspension of sediments…" Kalff, p86. Sediment mobilization in shallows and redeposition in deeper areas of the lake that are not influenced by wind-generated turbulence is called **sediment focusing**, which is particularly important in paleolimnology studies.

Width is the length of a line from shore to shore at right angles to the length.

Area (A) is the surface area of the lake.

Shoreline is the length of the shore line.

Volume (V) is the total volume of a lake. In practice, this is calculated from the bathymetric map as:

$V = \Sigma [A_1 + A_2 + \sqrt{(A_1 * A_2)}] \times h/3$, where:

A_1 = area of one contour,

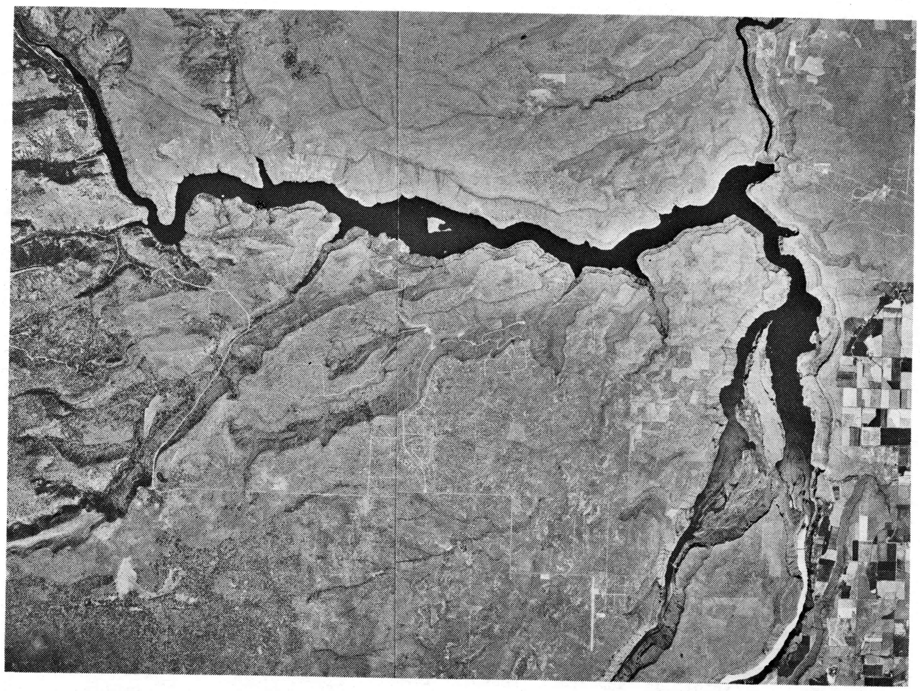
A_2 = area of the next contour

h = the thickness of the layer between the two contours.

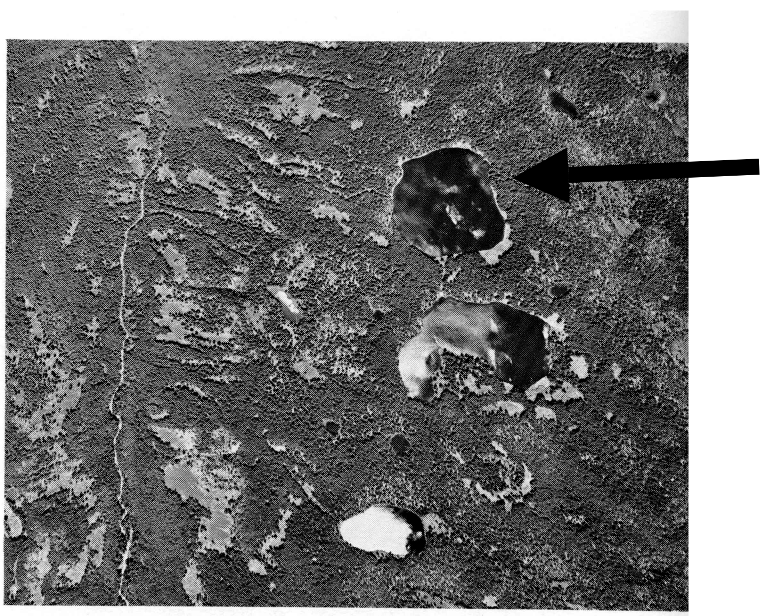
Mean depth (Z_{ave}) The volume divided by the area. ($Z_{ave}=V/A$). "Mean depth is probably the single most useful morphometric feature available." Kalff, p87.

Development of shoreline is the ratio of the shoreline length to the circumference of a circle with area equal to the area of the lake. That is, the lake shape is compared with an idealized shape (circle). That is:

$$D_L = L/(2 \sqrt{(\pi * A)})$$



Lake Billy Chinook. D_L=7.1



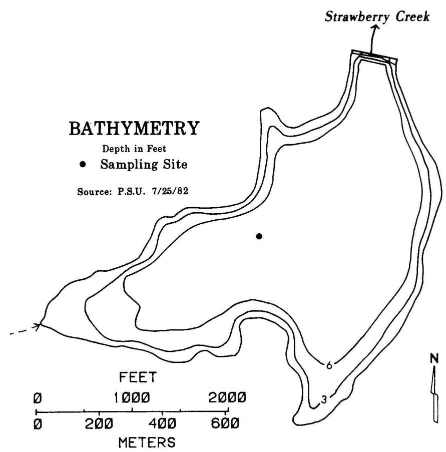
Lower Érma Bell Lake

D_L=1.06

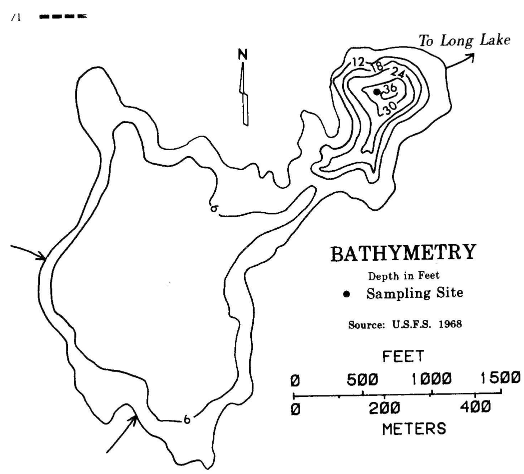
These lakes lie in the volcanic terrain north of Waldo Lake. Their shape suggests a volcanic origin, however, they were formed by glacier scouring.

Development of volume is the ratio of the volume of the lake to the volume of a cone of basal area equal to the surface area of the lake and height equal to the maximum depth. Or:

$D_V = (3*Z_{ave}/Z_{max})$



Strawberry Reservoir D_V=2.16 (Lies ~25 miles west of Lakeview)



Monon Lake, D_V=0.55 (Lies north of Mt. Jefferson)

Kalff suggests that the depth ratio (Z_{ave}/Z_{max}) is just as useful. (p88)

For most lakes Z_{ave}/Z_{max} is > 0.33, which is the value that would be given for a basin that was a perfect conical depression. The ratio exceeds 0.5 in many caldera, graben, and fjord lakes. Most lakes in easily eroded rock usually have ratios between 0.33 and 0.5. Very low values of the ratio occur only in lakes with deep holes, such as solution or kettle lakes.

3. Hypsographic curves

Hypsographic curves of area or volume vs. depth are often a useful way to depict shape relationships of a lake basin. ("Hypsographic" means "configuration of a land surface with respect to height".) For example, a hypsographic curve will identify depths at which there is more or less bottom sediment exposed. (see the bathymetric maps shown above)

Reservoirs are zoned lengthwise and typical "lake like" characteristics only occur near the dam where reservoirs are deepest

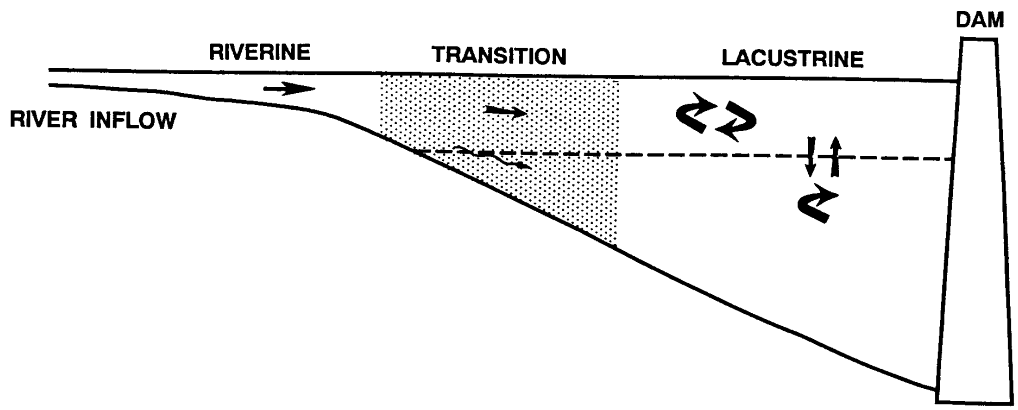


FIGURE 3-20 Generalized zones along longitudinal gradients in reservoirs.

TABLE 3-5 Comparative Hydrodynamic Characteristics among River, Reservoir, and Natural Lake Ecosystems[a]

	Rivers	*Reservoirs*	*Natural lakes*
Water level fluctuations	Large, rapid, irregular; flooding common	Large, irregular	Small, stable
Inflow	Overland and groundwater runoff; highly irregular and seasonal, less so with large groundwater inflows	Most runoff to reservoir via river tributaries (high stream orders); penetration into stratified strata complex (over-, inter-, and underflows); often flow is directed along old riverbed valley	Runoff to lake via tributaries (often low stream orders) and diffuse sources; penetration into stratified waters small and dispersive
Outflow (withdrawal)	Discharge highly irregular with inflows and precipitation event frequency	Highly irregular with water use; withdrawals from surface layers or from hypolimnion	Relatively stable; usually largely surface water via surface outflow or shallow ground water
Flushing rates	Rapid, unidirectional, horizontal	Short, variable (days to several weeks); increase with surface withdrawal, disruption of stratification with hypolimnetic withdrawal; three dimensional	Long, relatively constant (one to many years); three-dimensional

[a] Assembled from many sources and the syntheses on rivers of Ryder and Pesendorfer (1980) and on reservoirs and lakes by Wetzel (1990b).

TABLE 3-4 Comparative Geomorphological Characteristics and Properties among River, Reservoir, and Natural Lake Ecosystems[a]

Property	*Rivers*	*Reservoirs*	*Natural lakes*
Drainage basins	Many small tributaries coalesce into trunk stream; drainage area high in relation to surface area	Usually narrow, elongated lake basin in base or drainage area; area large in comparison to lake area (ca. 100:1 to 300:1)	Circular, lake basin usually central; drainage area usually small in comparison to lake area (ca. 10:1)
Shape	Long, meandering, linear rivers elongate as drainage basins increase in size	Variable, ovoid to triangular	Circular to elliptical predominate
Mean depth	Shallow in headwaters, increases to mouth	Shallow in riverine portions, increasing in lacustrine zones	Moderate to high; average less than 10 m
Depth gradient	Increases from headwaters to mouth	Increases from riverine through transitional to lacustrine zones	Deepest usually remote from shore line
Shoreline erosion and substrata distribution	Extensive, induced by water currents, gravity driven	Extensive in riverine areas by water currents; less from wind-induced currents in lacustrine zones	Localized, induced by wind-generated waves and currents
Shoreline development	Great, astatic	Great, astatic	Relatively low; stable
Sediment loading	High with large drainage basin area	Large with large drainage basin area; flood plains large; deltas large, channelized, gradation rapid	Low to very low; deltas small, broad, gradation slow
Deposition of sediments	Determined by water currents; highly variable with precipitation events	High in riverine zone, decreasing exponentially down reservoir; greatest in old riverbed valley; highly variable seasonally	Low, limited dispersal; relatively constant rates seasonally
Sediment suspended in water (turbidity)	High, variable	High, variable; high percentage of clay and silt particles; turbidity high	Low to very low; turbidity low

[a] Assembled from data of many sources particularly of the syntheses on rivers by Ryder and Pesendorfer (1989) and on reservoirs and lakes by Wetzel (1990b) and many references cited therein.

C. Lake morphology and lake ecology

A number of analyses have demonstrated relationships between lake morphology and other lake characteristics. Some examples:

Haakanson (1995) related water transparency (Secchi depth) to other lake characteristics. The most important predictors of transparency were lake color (Pt) and temperature. In addition…"The most important 'map' parameters are: The mean depth… and the ratio between the drainage basin area and lake area…" Haakanson, L. 1999 "Models to predict Secchi depth in small glacial lakes." Aquatic Sciences **57**:31-53

Fee et al (1996) evaluated the relationship between temperature stratification and lake morphology. "Over the full spectrum of lake sizes, A_0 [surface area] was the primary determinant of E_d [depth of the mixed layer]; transparency significantly modified this relationship but only in small lakes…" Fee, E.J et al. Symposium on Regional Assessment of Freshwater Ecosystems and Climate Change in North America, Leesburgh, VA 24-26 August, 1994 "Effects of lake size, water clarity, and climate variability on mixing depths in Canadian Shield lakes."

Blais, J.M. 1995 reported that sediment focusing is related to basin morphology. Blais and Kalff 1995: L&O 40:582-588. "The influence of lake morphometry on sediment focusing." [Results important to paleolimnology.]

Allan et al (1999) demonstrated a relationship between lake morphology (area, depth) and patterns of taxonomic species richness for macroinvertebrates, fish, diatoms and other taxa. Lake area was the most influential morphological characteristic. Authors noted that lake morphology was a stronger influence on species richness than was human development of the watershed.