# Age

Encyclopedia of Estuaries
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# AGE

## Definition

*Age*. The time elapsed since a water parcel or constituent particle entered a defined water body (Bolin and Rodhe, 1973; Zimmerman, 1976; Takeoka, 1984).

## Essential concepts, applications and methods of estimation

"Age" is a hydrodynamic transport time scale commonly used to characterize the time elapsed between release of a substance (e.g., a pollutant) into a water body and its arrival at a location of concern (Shen and Haas, 2004). Parcels and particles may be released from origin *regions* as well as point sources; therefore, in addition to the definition provided above, age has also been defined as the time elapsed since a parcel or particle left the region in which its age is prescribed to be zero (Delhez et al., 1999; Deleersnijder et al., 2001). As the time taken by a parcel since entering a water body to reach location **x**, age is commonly considered the complement to "residence time," if residence time is defined as the time taken by a water parcel originating at **x** to leave the water body; the sum of the two time scales is called "transit time" (Takeoka, 1984; Sheldon and Alber, 2002).

Age is unique to each water parcel, spatially heterogeneous within a water body (Monsen et al., 2002; Banas et al., 2007), dependent on source location (Zimmerman, 1976; de Brye et al. 2012), and time-dependent (Delhez et al., 1999). Moreover, given that diffusive processes can cause exchange of particles between fluid parcels as they travel through a water body, a parcel is likely to contain particles of different ages (Deleersnijder et al., 2001). Also important are the facts that (1) water is a mixture of different constituents including pure water, salts, dissolved chemicals, biological and mineral particulates, and chemicals sorbed to particles, and (2) age of each constituent varies in space and time (Delhez et al., 1999; Delhez and Wolk, 2013). These different constituents are subject to their own unique production and destruction processes, further altering distributions of particle histories---and therefore ages---within a given water parcel (Deleersnijder et al., 2001).

Age is one of several diagnostic transport time scales that can be estimated to distill the details of estuarine hydrodynamic circulation and exchange, and to aid in the understanding of linked physical, biological, and chemical processes (e.g., Banas et al., 2007; Lucas et al., 2009; Delhez and Wolk, 2013). This time scale can be used, for example, to backcast release times for substances detected in particular locations (Delhez and Deleersnijder, 2002); assess locations and times of increased estuary vulnerability to river-derived nutrient inputs (Shen and Haas, 2004); understand spatial variations in larval settlement (Banas and Hickey, 2005); and interpret complex hydrodynamic circulation patterns (Deleersnijder et al., 2001; Andutta et al., 2013). Age of water parcels originating at the water surface ("ventilation age", DeVries and Primeau, 2010) is also commonly used to provide insight into ventilation rates in ocean basins (Haine and Hall, 2002; Mouchet and Deleersnijder, 2008).

In estuaries, variability in age may be influenced by freshwater discharge (de Brye et al., 2012), gravitational circulation and stratification (Shen and Haas, 2004), wind (Andutta et al., 2013), bathymetry (Shen and Haas, 2004), tides (Banas and Hickey, 2005), and bottom friction (Andutta et al., 2013). Age is commonly computed with numerical models, using both traditional Lagrangian-based particle tracking techniques (e.g., Andutta et al., 2013) and Eulerian approaches (e.g., Delhez et al., 1999; de Brye et al., 2012). Models representing a broad range of complexity have been used to assess age, including box (Zimmerman, 1976), one-dimensional (Mouchet and Deleersnijder, 2008; Delhez and Wolk, 2013), two-dimensional (Monsen et al., 2002), and three-dimensional (Shen and Haas, 2004) models. Age may also be assessed in the field using substances such as passive dyes (Kratzer and Biagtan, 1997) and radioactive tracers (Delhez et al., 2003; de Vries and Primeau, 2010; Xu et al., 2013).

**Summary**

Age is a hydrodynamic transport time scale used to convey the time elapsed since a water parcel or particle was introduced to a defined water body. This time scale may be estimated using field or computational techniques to gain insight into the transport and dynamics of substances such as pollutants that are released into surface waters. Age is also used as an interpretive tool for better understanding complex hydrodynamic flows.

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**Bibliography**

Andutta, F. P., Ridd, P. V., Wolanski, E., 2013. The age and the flushing time of the Great Barrier Reef waters. Continental Shelf Research, 53: 11-19.

Banas, N. S., Hickey, B. M., 2005. Mapping exchange and residence time in a model of Willapa Bay, Washington, a branching, macrotidal estuary. Journal of Geophysical Research, 110: C11011.

Banas, N. S., Hickey, B. M., Newton, J. A., Ruesink, J. L., 2007. Tidal exchange, bivalve grazing, and patterns of primary production in Willapa Bay, Washington, USA. Marine Ecology Progress Series, 341: 123-139.

Bolin, B., Rodhe, H., 1973. A note on the concepts of age distribution and transit time in natural reservoirs. Tellus, 25: 58-62.

de Brye, B., de Brauwere, A., Gourgue, O., Delhez, E. J. M., Deleersnijder, E., 2012. Water renewal timescales in the Scheldt Estuary. Journal of Marine Systems, 94: 74-86.

Deleersnijder, E., Campin, J.-M., Delhez, E. J. M., 2001. The concept of age in marine modelling I. Theory and preliminary model results. Journal of Marine Systems, 28: 229-267.

Delhez, E. J. M., Campin, J.-M., Hirst, A. C., Deleersnijder, E., 1999. Toward a general theory of the age in ocean modelling. Ocean Modelling, 1: 17-27.

Delhez, E. J. M., Deleersnijder, E. 2002. The concept of age in marine modelling II. Concentration distribution function in the English Channel and the North Sea. Journal of Marine Systems, 31: 279-297.

Delhez, E. J. M., Deleersnijder, E., Mouchet, A., Beckers, J.-M., 2003. A note on the age of radioactive tracers. Journal of Marine Systems, 38: 277-286.

Delhez, E. J. M., Wolk, F., 2013. Diagnosis of the transport of adsorbed material in the Scheldt estuary: a proof of concept. Journal of Marine Systems, 128:17-26.

DeVries, T., Primeau, F., 2010. An improved method for estimating water-mass ventilation age from radiocarbon data. Earth and Planetary Science Letters, 295: 367-378.

Haine, T. W. N., Hall, T. M., 2002. A generalized transport theory: water-mass composition and age. Journal of Physical Oceanography, 32:1932-1946.

Kratzer, C. R., Biagtan, R. N., 1997. Determination of traveltimes in the Lower San Joaquin River Basin, California, from dye-tracer studies during 1994-1995. U.S. Geological Survey Water-Resources Investigations Report 97-4081.

Lucas, L. V., Thompson, J. K., Brown, L. R., 2009. Why are diverse relationships observed between phytoplankton biomass and transport time? Limnology and Oceanography, 54(1): 381-390.

Monsen, N. E., Cloern, J. E., Lucas, L. V., Monismith, S. G., 2002. A comment on the use of flushing time, residence time, and age as transport time scales. Limnology and Oceanography, 47(5): 1545-1553.

Mouchet, A., Deleersnijder, E., 2008. The leaky funnel model, a metaphor of the ventilation of the World Ocean as simulated in an OGCM. Tellus, 60A: 761-774.

Sheldon, J. E., Alber, M., 2002. A comparison of residence time calculations using simple compartment models of the Altamaha River Estuary, Georgia. Estuaries, 25(6B): 1304-1317.

Shen, J., Haas, L., 2004. Calculating age and residence time in the tidal York River using three-dimensional model experiments. Estuarine, Coastal and Shelf Science, 61: 449-461.

Takeoka, H., 1984. Fundamental concepts of exchange and transport time scales in a coastal sea. Continental Shelf Research, 3(3): 311-326.

Xu, B.-C., Dimova, N. T., Zhao, L., Jiang, X.-Y., Yu, Z.-G., 2013. Determination of water ages and flushing rates using short-lived radium isotopes in large estuarine system, the Yangtze River Estuary, China. Estuarine, Coastal and Shelf Science, 121-122: 61-68.

Zimmerman, J. T. F., 1976. Mixing and flushing of tidal embayments in the western Dutch Wadden Sea Part I: Distribution of salinity and calculation of mixing time scales. Netherlands Journal of Sea Research, 10(2): 149-191.

**Cross References**

Time scale
Residence time