Residence time

Encyclopedia of Estuaries
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RESIDENCE TIME

Definition

Residence time is defined as (1) the time taken by a water parcel or particle to leave a defined region of interest (Zimmerman, 1976; Delhez et al., 2004; de Brauwere et al., 2011) or (2) the time for the mass of a scalar (or the volume of freshwater; Dyer, 1997; Geyer, 1997) within a water body to be renewed, given a known renewal rate (Bolin and Rodhe, 1973; Geyer et al., 2000).

Essential concepts, applications and methods of estimation

"Residence time" is a commonly used term to generally convey time spent by water, dissolved substances, or particles within a defined region or water body. However, specific definitions and mathematical descriptions of this transport time scale vary considerably in the literature, as pointed out by others (Takeoka, 1984; Monsen et al., 2002; Sheldon and Alber, 2002). The definitions provided above are two of the most common and differ significantly from each other in their underlying assumptions, precise meanings, and methods of estimation. Care is needed in the selection and description of residence time and other transport time scale definitions and calculation methods, as estimated values and suitability for the scientific question at hand can vary substantially between approaches (Bolin and Rodhe, 1973; Monsen et al., 2002).

Following from the first definition above (i.e., the time taken by a water parcel or particle to leave a defined domain), residence time is a function of space and time of release, since particles originating at different locations and times within a water body require different amounts of time to leave (Monsen et al., 2002; Delhez et al., 2004). Defined in this way, residence time (time for a parcel originating at location **x** to exit a domain) is the complement of "age" (time the parcel took to reach **x** after entering the domain); the sum of the two time scales is called "transit time" (Takeoka, 1984; Sheldon and Alber, 2002). In tidal systems, ambiguity in the application of this definition may arise due to the fact that fluid elements may leave the region of interest on one phase of the tide, then re-enter when the tide reverses. Therefore, many authors have employed a strict interpretation of this definition: the time required for a parcel to leave the domain *for the first time* (Monsen et al., 2002; Delhez et al., 2004; de Brauwere et al., 2011). Because the cumulative amount of time spent within a water body (over successive tidal visits) may be of ecological interest, a variation on the residence time concept---"exposure time"---has been defined and computed with numerical models (e.g., Monsen et al., 2002; de Brauwere et al., 2011). A variety of numerical approaches is employed to assess this first type of residence time, including Lagrangian particle tracking (Monsen et al., 2002), forward Eulerian (de Brauwere et al., 2011), and time-reversed Eulerian (Delhez et al., 2004) methods, the latter approaches making use of numerical tracers. Models representing a broad range of complexity have been implemented for this purpose, including box (Zimmerman, 1976), one-dimensional (Vallino and Hopkinson, 1998), two-dimensional (de Brauwere et al., 2011), and three-dimensional (Shen and Haas, 2004) models.

The second residence time definition (i.e., the time for scalar renewal) represents an integrative time scale describing general exchange characteristics of water bodies without addressing spatial variability (Monsen et al., 2002). Under steady-state conditions, residence time defined in this way takes the simple form M/F, where M is total scalar mass in a domain and F is the scalar rate of renewal (Bolin and Rodhe, 1973; Geyer et al., 2000). If freshwater renewal is of particular interest, freshwater volume may substitute for M and freshwater flow rate for F (Dyer, 1997; Geyer, 1997). These integrative time scales are also known as "flushing times" (Monsen et al., 2002; Sheldon and Alber, 2002) or "turnover times" (Bolin and Rodhe, 1973; Sheldon and Alber, 2006).

Regardless of definition, residence time is frequently compared with biogeochemical time scales to evaluate the relative importance of physical, biological, and chemical processes in aquatic systems (Vallino and Hopkinson, 1998; Dame, 2012). Residence time can thus be used, for example, to understand the fate of pollutants (Jonkers et al., 2005), the modulation of algal growth and loss processes in regulating primary productivity (Lucas and Thompson, 2012), and nutrient export from estuaries to the continental shelf (Nixon et al., 1996). In estuaries, residence time may be influenced by a range of physical forcings including river flow (Shen and Haas, 2004), tides (de Brye et al., 2012), and wind stress (Geyer, 1997). The relative importance of drivers may vary between estuaries (Geyer et al., 2000), spatially within estuaries (Shen and Haas, 2004), and over time (de Brauwere et al., 2011). Although different transport mechanisms can result in similar residence times, their effects on water quality and ecosystem function may not be equivalent (Geyer et al., 2000).

Summary

Residence time is one of several "transport time scales" that can be estimated to distill hydrodynamic processes to better understand their importance relative to biological and chemical processes and their influence on water quality and ecosystem function. Multiple specific definitions of residence time may be found in the literature, all meant to generally convey time spent by water (and the particles and substances carried with it) inside a defined region. Two of the most commonly employed definitions have been described herein: 1) the time for a water parcel or particle to exit a defined water body; 2) time for the mass of a scalar or freshwater volume within a water body to be renewed. Methods for estimating residence times are highly varied, including field based (e.g., Geyer, 1997) and numerical (e.g., Delhez et al., 2004) approaches.

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Cross References

Time scale
Age