Low flows play a key role in structuring river ecosystems and maintaining populations of water-dependent plants and animals. A key limitation in research on effects of both low flows and flow alteration on river ecosystems is the lack of specific understanding of the underlying mechanisms or processes contributing to altered ecosystem structure and function. Here, we present five fundamental mechanisms and processes linking low flows with aquatic ecosystems. These mechanisms include habitat, dispersal and refugia food webs and nutrient transfer and physical-chemical water quality effects. We demonstrate how low flows favour biota adapted to maintain life-cycle processes in still or slow flowing habitats, and influence the longitudinal, lateral and vertical transport of nutrients to river ecosystems. We show how hydrological low flow attributes (e.g. duration of low flows, magnitude and antecedent conditions) link with the ecological mechanisms presented. Finally, we identify the threats and potential alterations on low flows, such as variations to catchment land use, climate change and water abstraction. This has application to the development of ecologically relevant water management decision making and identifies knowledge gaps requiring further scientific research.