Program 3: Surface Water–Groundwater Interactions
Program Leader: Professor Peter Cook (Flinders University/ CSIRO)
email: peter.g.cook@csiro.au

International Visiting Scholars: Dr Judson Harvey (USGS), Dr Randall Hunt (USGS), Prof. John Selker (Oregon State University), Prof. Alicia Wilson (Florida State University).

The interconnectivity of surface water and groundwater is often not fully recognised or accounted for by water managers, and this can lead to double accounting and double allocation of resources. This problem is compounded by a lack of widely available infrastructure for monitoring surface water–groundwater connections. Scientifically, because they are at the interface between surface water and groundwater hydrology, surface water–groundwater interactions still pose major research challenges. Understanding the spatial and temporal dynamics of surface water–groundwater interaction processes is a major research area (Sophocleous 2002). This research program will quantify fluxes and constrain biogeochemical processes and will provide important links to important groundwater dependent ecosystems; these are key gaps in current understanding and matters of critical international scientific interest. Attempts will be made to develop integrated concepts for the ecological assessment of connected surface water and groundwater. Importantly, through ecological and biogeochemical characterisation, this program will aim to determine whether ecological communities can be used to measure or indicate groundwater-surface water interactions. *Key investigators: PI Cook, PI Lamontagne CI Lockington, CI Simmons, CI Cartwright, CI Gasparon, with assistance from CI Acworth.*

Sub-program 3A: Groundwater recharge from losing streams. There are no accepted field methods for distinguishing between connected and disconnected streams, and currently-used theoretical criteria for assessment are now recognised to be in error (Brunner et al., 2009). Developing robust theoretical criteria to predict river connectivity remains a challenge. Field-based assessments of disconnected streams, and their transient nature, are absent in current literature since they lack a robust theoretical basis. An ability to make this distinction is vital for groundwater management, as groundwater pumping will only deplete streamflow if streams are hydraulically connected to the groundwater. This Sub-program will develop new theoretical criteria and urgently needed field methodologies (hydraulic, heat/thermal and hydrochemical) for assessing disconnection states between groundwater and losing streams. The rate of surface water loss will be measured using river flow gauging, and relationships between loss rate and surface water and groundwater levels will be explored using both modelling and hydraulic, chemical and tracer approaches. Improved methods for estimating connectivity and river losses are particularly needed in arid and semi-arid regions where ephemeral losing streams form a major recharge mechanism. The transient nature of these processes is a major challenge that will be overcome by sampling for both hydraulics and chemistry at high spatial and temporal resolution.

Sub-program 3B: Groundwater discharge to gaining streams. Chemical baseflow separation methods typically suggest that 30-70% of the streamflow peak that follows a rainfall event is attributable to groundwater baseflow. This contradicts hydraulic analyses, which suggest a large timelag between an increase in groundwater recharge resulting from the rainfall event and the corresponding increase in discharge to the stream (Kirchner, 2003). This paradox remains an important but unresolved scientific problem in the area of surface water–groundwater interaction. This Sub-program will investigate this paradox by conducting baseflow separation during storm events with a number of different tracers. These will include a combination of chloride and ^{2}H and ^{18}O, which are traditionally used for chemical baseflow separation, and novel tracers such as ^{222}Rn, He, and $^{3}H/^{3}He$, which allow groundwater residence times to be determined. This combination of tracers will allow for the critically needed differentiation between native groundwater and bank return flow, and allow mixing processes within the near-stream environment to be assessed. Groundwater levels during the stormflow event will also be measured in transects of nested piezometers, allowing directions of flow at different levels in the groundwater system to be monitored throughout the event. This will lead to a better understanding of the hydraulic and chemical exchange processes that occur during stormflow events, and also the ability of chemical methods to accurately partition storm hydrographs. These issues also apply to lake and wetland systems, which have received relatively little study, and where hydraulic and tracer approaches yield different fluxes (Hunt et al., 1996).

Sub-program 3C: River – Hyporheic exchanges. While river–hyporheic exchanges are known to be important regulators of subsurface biochemical transformations, the manner in which these processes vary spatially and temporally requires further research. In particular, understanding the extent to which hyporheic processes are influenced by groundwater inputs remains a key challenge. This Sub-program will refine our understanding of the vital controls on hyporheic exchange processes in order to further understand the links between net groundwater exchange with a river and the more transient hyporheic exchange process. It will examine water residence times in hyporheic and near-stream environments, and the relationships between residence time and biogeochemical processes. These have important impacts on water quality (e.g., nutrient loading) and ecological activity along river-groundwater exchange zones. Residence time will be estimated using artificial tracers (timescale of hours), and environmental tracers ^{222}Rn (days), and $^{3}H/^{3}He$ (months to years). Hydraulic gradients will be measured with mini-piezometers, so that residence times can be linked to zones of up-welling and downwelling groundwater, and measurement will also be made of key geochemical parameters (e.g. dissolved oxygen, organic matter content). The outcome will be an improved understanding of how river–hyporheic exchanges vary across riverine environments, and the relationship between river–hyporheic exchanges and large scale variations in groundwater inflow or outflow rate.

Sub-program 3D: Groundwater interaction with estuarine rivers, lakes and wetlands. Australia's extensive coastline, including a large number of islands, gives rise to an enormous range of tropical to sub-Antarctic terrestrial and shallow water conditions and habitats, which in turn are home to complex and sensitive ecosystems of rich biodiversity, and subject to major development and climate change impacts. Tidal forcing, chemical and density contrasts between seawater and terrestrial groundwater and complex hydrogeology characterise the hydrology of these systems. This Sub-program will significantly advance the fundamental quantitative understanding of the groundwater dynamics, biogeochemistry and ecology of estuarine rivers, lakes and wetlands. The results of this program are critical to global understanding and management of these vital and threatened ecological and hydrological systems. The composition and distribution of biota in benthic and riparian zones in estuaries are sensitive to salinity distributions as well as the magnitude, chemistry and spatial distribution of discharging groundwater. Recent studies have also shown that wetland and lake water balances may be used to link hydrogeological processes with ecological effects. Estuarine systems provide breeding and life cycle habitats for a wide range of important, sensitive biota (e.g. crustaceans, fish, mangroves, and seagrasses). Preliminary field and modelling investigations have identified new riparian-hyporheic circulation patterns that vitally affect ecological functioning (Werner and Lockington, 2006). Despite the importance of groundwater and nutrient fluxes for these complex environments, the dynamics of these processes in coastal environments are poorly understood and unable to be reliably quantified. Major knowledge gaps relate to: (1) the effect of tidal, variable salinity estuary and lake hydrodynamics on groundwater discharge and estuarine water recirculation; (2) the consequences of the hydrodynamics and exchange on residence times and groundwater biogeochemical processes; and (3) the ability to properly model and quantify these complex processes and implications for ecosystem functioning. This research will advance our knowledge of the hydrological, ecological and biogeochemical functioning of estuarine systems using field, laboratory and surface water-groundwater modelling approaches.