BHS 2014

Session 4: Water quality responses to environmental change

ABSTRACTS

Oral presentations

4-1L: Reducing diffuse nitrate pollution in an intensive arable catchment: an interdisciplinary approach

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The increase in reactive nitrogen in the environment from the application of nitrogenous fertilisers has negatively impacted the aquatic environment through eutrophication. Tackling this issue while maintaining food production for an increasing global population is a pressing challenge and one that requires an interdisciplinary approach. Since 2010, the UK government has funded the Demonstration Test Catchments (DTCs) programme to trial mitigation measures and test their efficacy in reducing diffuse pollution from agriculture. Each catchment has established a network of bankside monitoring stations and other infrastructure to determine the hydrological functioning, water quality and ecological status of specific subcatchment areas in the Eden, Hampshire Avon and Wensum catchments in England. In the Wensum DTC in the east of England, a team of researchers and agronomists with a range of disciplinary interests has uniquely collaborated to trial measures such as cover cropping and direct drilling to reduce nitrate leaching losses. A programme of soil water and drain flow monitoring, together with analysis of farm business data, is providing insight into how such measures can be cost-effectively incorporated into an arable crop rotation. Results after one year of implementing the measures shows success in the incorporation of cover cropping in substantially reducing nitrate leaching losses but with some evidence of 'pollution swapping' in respect of direct and indirect nitrous oxide emissions.

4-2L: Monitoring urban water quality using a tryptophan-like fluorescence sensor platform

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Due to the recent development of field-deployable optical sensor technology, continuous quantification and characterization of surface water dissolved organic matter (DOM) is possible now. Tryptophan-like (T_1) fluorescence has the potential to be a particularly useful indicator of human influence on water quality as T_1 peaks are associated with the input of labial organic carbon (e.g. sewage or farm waste) and its microbial breakdown. Hence, real-time recording of T1 fluorescence could be particular useful for monitoring waste water infrastructure, treatment efficiency and the identification of contamination events at higher temporal resolution than available hitherto. However, an understanding of sensor measurement repeatability/transferability and interaction with environmental parameters (e.g. turbidity) is required. Here, to address this practical knowledge gap, we present results from a rigorous test of a commercially available submersible tryptophan fluorometer (λex 285, λem 350). Sensor performance was first examined in the laboratory by incrementally increasing turbidity under controlled conditions. Further to this the sensor was integrated into a multi-parameter sonde and field tests were undertaken involving: (i) a spatial sampling campaign across a range of surface water sites in the West Midlands, UK; and (ii) collection of high resolution (sub-hourly) samples from a small urban stream (Bournbrook, Birmingham, U.K). For each site or discrete time step DOM was characterized, using Excitation Emission Matrix spectroscopy and peak picking, to determine the ability of the sensor to capture spatiotemporal dynamics of urban waters. In the laboratory setting, fluorescence intensity was attenuated at high turbidity due to suspended sediments (SS)

increasing primary and secondary inner filtering. However, at lower turbidity (i.e. SS <2000mg L^{-1}) intensity was increased, possibly due to increased inelastic scattering. For the spatial survey, instrument readings were compared to those obtained by a laboratory grade fluorometer (Varian Cary Eclipse) and a strong, linear relationship was apparent (R2 > 0.7). Parallel water sampling and laboratory analysis identified the potential for correction of T_1 fluorescence intensity based on turbidity readings. These findings highlight the potential utility of real time monitoring of T_1 fluorescence for a range of environmental applications (e.g. monitoring sewage treatment processes and tracing polluting DOM sources). However, if high/variable suspended sediment loads are anticipated concurrent monitoring of turbidity is required for accurate readings.

4-3L: Longitudinal Water Temperature and Heat Flux Patterns within a Semi-Natural Forested Stream Reach

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Previous studies have suggested that riparian vegetation can reduce maximum water temperatures and provide refugia for temperature sensitive organisms. Longitudinal cooling gradients have been observed during the daytime for stream reaches shaded by conifer trees downstream of clear cuts, or deciduous woodland downstream of open moorland. Little is known about the energy exchange processes that drive such gradients, especially in semi-natural woodland, and in the absence of potentially confounding cool groundwater inflows. This study characterised variability in water temperature and heat fluxes for an upland reach of the Girnock Burn (a tributary of the Aberdeenshire Dee, Scotland) where riparian landuse transitions from open moorland to semi-natural forest. Observations were made along a ~1000 m reach using a spatially-distributed network of ten water temperature micro-loggers, three automatic weather stations and ca. 200 hemispherical photographs which were used to scale incoming radiation. These data were used to parameterise a high resolution energy flux model incorporating flow-routing that predicted spatio-temporal variability in stream temperature and which was able to identify the processes underlying observed temperature variability. For periods when daytime net radiation gains were high (i.e. clear skies), instantaneous temperature gradients of up to 2.5 °C were observed in the streamwise direction. These temperature gradients were not generated by cooling of stream water, but rather by a combination of lower rates of heating in the woodland reach and lagged overnight temperatures from the upstream moorland catchment. Longitudinal thermal gradients were indistinct at night or on days when net radiation gains were low (i.e. over-cast sky conditions). The findings of the study and the modelling approach employed are useful tools for assessing optimal planting strategies for mitigating against ecologically damaging stream temperature maxima.

4-4S: Assessing the water quality response to the UK winter 2013/2014 floods in contrasting urban catchments

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The intensity and clustering of storms that affected the UK during the winter months of 2013/14 resulted in unprecedented flooding to southern areas of England and Wales (Met Office, 2014). The relentless succession of rain events resulted in perpetually saturated landscapes, where smaller magnitude storm events resulted in further increases to river levels in already flooded areas. Much of the discussion that arose in response to these events centred on the magnitude of flood waters and the techniques for remediation of future events but equally important is the water quality conditions of stormwater, which has received less attention.

Here, we present water quality data from this period from seven sub-catchments across two urban areas (Bracknell and Swindon) as part of a unique, high-resolution (15 minute) monitoring strategy. This monitoring regime forms part of the NERC Changing Water Cycle programme that aims to determine and predict the impacts of urbanisation on hydrological dynamics and water quality (POLLCURB). Dominant catchment land use varies and contrasting levels of urbanicity are evident across the seven sub-catchment areas, where large portions of grassland, forestry and arable/horticultural land are all present. The resulting dataset presents a unique opportunity to characterise the first flush response of contrasting urban areas and assess the water quality response as a result. The results show marked differences in the concentrations and temporal dynamics of water quality metrics across these sub-catchments, providing a novel insight into the land uses where contributions to water quality degradation are most significant during high-magnitude events.

4-5S: Developing a framework for including uncertainty analysis in the evaluation of high frequency data to estimate catchment nutrient fluxes and behaviour.

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Changing climate and population growth are increasing pressures on the world's water bodies and current agricultural practices are leading to adverse impacts on water quality. The use of in-situ quasi-continuous monitoring of water quality is held to improve the characterisation of pollutant behaviour and provide new insights into catchment hydrological and biogeochemical processes.

Previous research into nutrient flux estimation has focused on assessing the uncertainty associated with interpolation or extrapolation load estimation methods. During such work, high resolution synchronous paired discharge and nutrient concentrations are often used as a benchmark of 'truth' against which non-synchronous and lower resolution data strings are tested. This work challenges the assumption of 'truth' and demonstrates the importance of analyzing uncertainties associated with high-temporal resolution discharge and nutrient data to characterise the range of robust flux estimates .

For this purpose, this study uses high resolution (15 or 30 min) data from four field sites collected as part of the Hampshire Avon Demonstration Test Catchment project between 2011-2013. These data illustrate seasonal channel dynamics and highlight why the use of a single stage-discharge curve for discharge estimation is often inappropriate in small headwater research catchments. A statistical approach was taken to quantify the uncertainty in all parameters, which were then used to assess the impact of the uncertainty on the estimation of nutrient fluxes. The results highlight the importance of acknowledging all observational uncertainty, even when using high temporal resolution datasets if a robust assessment of catchment behaviour is to be gained.

4-6S: Diffuse pollution in groundwater-dominated agricultural catchments

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High-frequency *in situ* nutrient monitoring reveals patterns of nutrients concentration changes that are not captured by the infrequent routine monitoring. Based on high-frequency data important insights have been gained into nutrient behaviour including fractal, non-self-averaging and chemostatic behaviour and seasonal succession of nutrient responses controlled by seasonal changes in nutrient sources, mobilisation and delivery. In groundwater-dominated catchments nutrient sources can potentially be distant in space and time from the locations in the stream network where their negative impact is observable or measurable. Intensive in-stream processing including biological uptake, sediment binding and nutrient attenuation along the subsurface pathways can play an important role in controlling diffuse nutrient delivery in groundwater-dominated catchments. In this paper we discuss the role of transient storage on the nutrient export regimes and their implications for nutrient monitoring. Our study is based on a long-term high-frequency biogeochemical monitoring of a small agricultural catchment with intensive groundwater-surface water interactions.

4-7S: Phosphorus transport under extreme events: analysis of high-frequency data from the River Eden catchment, Cumbria

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A major source of nutrients in British waterways is agricultural soil, fertilisers and manures washed off in storms. Too much phosphorus in rivers causes poor water quality with excessive plant growth, which can suffocate fish and other organisms. However, the mechanisms of phosphorus mobilisation and delivery to rivers are incompletely understood, and understanding of high frequency dynamics has been limited by data of insufficient temporal resolution. This study describes analysis of high frequency data of rainfall, river discharge, total phosphorus and total reactive phosphorus concentrations from the River Eden catchment, Cumbria, collected by the Defra Demonstration Test Catchment Programme. The analysis focussed on extreme events and event sequences, which are predicted to occur more frequently under a changing climate, such as periods of drying followed by heavy rainfall. More than 75% of the total phosphorus load was transported during the 5% of the time with highest river discharge. High phosphorus concentrations in the river were also recorded during rainfall events following a dry period, when there was little response in discharge. Improved understanding of these processes will contribute to

better predictions of phosphorus transfer under climate change and allow farmers to plan appropriate land management.

4-8S: The use of dynamic models to investigate the driving processes behind long-term fluctuations in P-export

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Long term changes in phosphorus (P) availability can be detrimental to the environment, as P is an essential nutrient for ecosystem functioning. Since 1978 significant, highly variable declines in aquatic P concentrations have been observed in the Muskoka region (Canada). We use dynamic models (INCA-P) to investigate the driving processes behind these changes, focusing upon the Dickie Lake watershed. Changes in climate, P deposition, hydrology and landuse (soil P inputs, processes, and outputs) were examined from 1978-2007; however, only changes in P storage and processes within wetlands could account for observed changes in net P export from the watershed. Changing processes are attributed to gradual recovery from historic disturbance events (pre-monitoring records), which caused extensive tree deaths in wetlands proximal to the lake. Observed P-declines may represent a return to a pre-disturbance natural baseline, with P exports decreasing over the study period as wetlands recovered. Model outputs from sub-catchments with greatest P-declines (154.8 kgP), indicate these initial high exports are attributable to low plant uptake (2.2 kgP) and P inputs from decaying plant material (60 kgP), of which ~1/3 directly impacted stream water quality. Elevated soil equilibrium concentrations during the disturbance period, an indirect result of the higher P inputs, account for a further 128.8 kgP of change. Whilst further P declines were not projected under future climate change (2071-2100), modelled future disturbance events (urbanisation, wetland drainage, and expansion of lake areas during future flood events) did result in P increases. The study highlights the importance of wetland maintenance in ecosystem stability.

4-9S: Modelling water quality in UK upland streams using high-frequency observations

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The behaviour of water quality parameters in upland streams can be highly dynamic, particularly through storms. To model these systems for understanding and predicting water quality response to changing environmental conditions (e.g. climate change, land cover change), it is necessary to have *high-frequency* water quality observations that capture the dynamics through contiguous storm events. As monitoring technology continues to improve such data are becoming increasingly available. A major water quality monitoring program in streams surrounding Llyn Brianne reservoir (Cambrian Mountains, UK) began in 2012, and aims to develop understanding of the relationship between catchment hydrological functioning and biogeochemical response. In four streams, 15-minute hydro-chemical data are being collected (including pH, DOC and NO_3-N). Novel continuous-time transfer function modelling of the H^+ and DOC observations (using the CAPTAIN toolbox) illustrate that solute concentration and load responses can be readily quantified from a rainfall input, and model characteristics are interpretable hydrologically. These models are parsimonious, have constrained uncertainty and make no *a priori* assumptions about the system complexity (e.g.

number of flow pathways), but instead are derived directly from the information within the observations. Analysis of the dynamic response characteristics of these models reveals that the use of anything other than sub-daily, and in some cases, sub-hourly observations, would have distorted the simulation of the H^+ and DOC dynamics, leading to subsequent misinterpretation of water quality responses. As such, water quality datasets that lack such high-frequency sampling may not be suitable for modelling hydrological controls on water quality dynamics in upland streams.

Poster presentations

4-1P: Investigation of industrial estate surface water outfalls: Monitoring, modelling and site management to mitigate pollution sources.

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The European Water Framework Directive (WFD) requires that all water bodies need to achieve 'good' status by 2015. In order to meet this requirement, sources of pollution to the water bodies have to be identified and adequate mitigation measures put in place so that the relevant water quality standards are met.

As part of their quality and standards programme for the period of 2010-2014, Scottish Water agreed with the Scottish Environment Protection Agency (SEPA) to address unsatisfactory discharges at six surface water outfalls from industrial and retail estates in Scotland that are suffering from diffuse sources of pollution. The pollutants include priority and priority hazardous substances which were specifically selected for the WFD as they present a significant risk to or via the aquatic environment.

This paper describes how monitoring and modelling have been combined with site visits and trader surveys to develop innovative Surface Water Action Plans (SWAPs) that assess the most cost-effective pollution mitigation measures to treat diffuse pollution from the surface water outfalls, in order to meet WFD requirements. The staged process identified then confirmed or screened-out potential sources of pollution, to identify interacting sources of pollution. This means that the SWAPS are useful tools for appropriate water management at each site. They recommend short, medium and long term actions that rest with SEPA, the local authority, site owners, or individual traders and will be evaluated periodically to keep the SWAP both effective and relevant to changing environmental conditions.

4-2P: Influence of riparian shading scenarios on stream heat exchange processes and water temperature dynamics

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There is substantial scientific and practical interest in the potential of shading by riparian vegetation to mitigate climate change impacts on stream temperature, especially maximum temperatures. This study uses water temperature and energy exchange observations in conjunction with hemispherical photographs taken along a ~1000 m reach of the Girnock Burn: a tributary of the Aberdeenshire Dee, Scotland, where riparian landuse transitions from open moorland to semi-natural woodland. Field data were used to underpin a simulation experiment of the effects of contrasting riparian vegetation shading regimes (open to 90% shade) on heat exchange and stream temperature dynamics within the reach. Nine hemispherical images, each representing increasing degrees of canopy openness were used in turn to paramterise a deterministic net radiation model and simulate radiative fluxes associated with reforestation of the reach. The effects of vegetation orientation relative to the sun's path were also investigated by changing the location of North in each image at 45-degree intervals. Simulated radiative fluxes plus measured sensible, latent and bed heat fluxes drove a Lagrangian water temperature model that predicted spatio-temporal variability

in stream temperature. Clear increases in mean (> 3.0 °C) and maximum (> 12 °C) temperatures were observed as canopy openness increased. When the reach was either very densely vegetated (canopy openness 10-30 %) or very sparsely vegetated (> 70%) the orientation of vegetation relative to the sun's path had no significant effect on radiative fluxes and water temperature. Intermediate levels of shade (canopy openness 40-70 %) produced highly variable radiative flux and water temperature dynamics, as a result of variability in the time of day the vegetation shaded the stream. The findings may be used to inform optimal planting strategies for mitigation of potentially ecologically damaging stream temperature maxima.

4-3P: Predicting future change in water flows and quality in the River Thames basin

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Despite substantial improvements in the recent past brought about by investment in treatment of sewage and industrial wastes and various incentives and regulations to reduce diffuse pollution, water quality in the UK is facing considerable future pressures. Using a model chain comprising (i) the Hadley Centre regional climate model, (ii) a rainfall-runoff model (CLASSIC) and (iii) a river quality model (QUESTOR), the impacts of changes in climate on water quality in the River Thames are predicted to be considerable. Notwithstanding model uncertainties, an increase in the frequency of "undesirable" conditions (as informed for example by UK targets to meet the EU Water Framework Directive) of between 5 and 30 days per year for water temperature, biochemical oxygen demand, dissolved oxygen and chlorophyll-a (phytoplankton) seems likely. These predictions however, do not consider the impact of population growth. Identifying the stress on water resources that a future increase in urbanisation will bring is the focus of the POLLCURB project (funded under the NERC Changing Water Cycle programme). To better understand effects of urbanisation, long-term flow and quality data in two sub-catchments of the Thames that have undergone rapid population growth in the last 50 years are being collected and assessed. This process will entail training a cellular automata landuse change model and test sub-catchment-scale models of hydrology, urban water management, sediment transport and water quality. A simplified representation of these models will be developed and used to refine the existing predictions of future change in water resources across the whole Thames basin.

4-4P: A novel approach for the design of large scale river temperature monitoring networks

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Water temperature is an important control on physical, chemical and biological processes in freshwater systems. Temperature is particularly important to poikilothermic species, such as salmonids, affecting growth, survival and demographic characteristics. In recognition of the importance of these issues CAMERAS (Coordinated Agenda for Marine, Environment and Rural Affairs Science) prioritised the development of a national water temperature network in the recently published Freshwater Monitoring Action Plan (MAP). Advances in geographical information systems (GIS), spatial statistics and dataloggers mean large scale river temperature monitoring is possible. However, many monitoring networks duplicate sites with similar environmental and thermal characteristics, leading to lower than expected statistical power to identify and model landscape and climate controls. This poster presents the novel methodology used to design Scotland's national temperature monitoring network. A literature review identified the landscape and climate variables controlling stream temperature. These characteristics were defined for points on a river network at 500m intervals. Finally a sub-set of points were chosen for logger deployment based on unique combinations of controlling variables. Consequently, a network has been developed with minimal redundancy that is anticipated to have high statistical power, to separate the relative importance of predictor variables, allowing large scale stream temperature predictions. This network will (1) characterise spatial-temporal variability (2) highlight areas of thermal sensitivity and (3) identify optimum areas for riparian tree planting. In the long-term the network will provide continuous monitoring of environmental change, from a representative network of sites, likely covering the range of responses expected across Scotland.

4-5P: Broadening the applicability of flux and solute transport models: a semi-distributed approach integrating Lagrangian and Eulerian frameworks. Applications to modelling the impacts of environmental change.

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Hydrological and water quality models have traditionally made use of an "Eulerian" framework that applies bulk mean pore velocities to approximate solute transport and wave celerities to predict the transmission of storage disturbances. These allow the medium to large scale application of such models, but at the expense of their ability to represent the soil heterogenities affecting the near-surface pathways that comprise the majority of the transport.

In contrast, a discrete representation of solute transport using a Lagrangian approach that tracks the locations of individual transport "fluxions" allows the effect of heterogenities and transitions between soil layers and mobile and immobile storage to be modelled. Reconciling these approaches is difficult due to the computational overhead involved in representing the total mass flux as well as the solutes transmitted. Recent work by e.g. Davies, Beven et al (2011) has demonstrated how this can be achieved in a small catchment, but scalebability remains an issue.

We demonstrate the initial results from a model that draws on Davies and Bevens' work but uses an extension to a semi-distributed hydrological model (Dynamic TOPMODEL, Beven and Freer, 2001, Metcalfe, Beven and Freer, 2014) to provide flux and storage predictions and to inform the velocities of entrained solutes within a discrete

transport representation.

The semi-distributed nature of the underlying hydrological model allows the problem domain to be radically simplified whilst maintaining information about catchment connectivity. It allows the introduction of response units of arbitrary scales representing significant diffuse and point pollutant sources and areas with high hydrological impact. In addition, the computational demands are significantly reduced compared to a full-distributed model allowing multiple runs within a broad parameter space .

We demonstrate how this approach can thus be applied to model a variety of scenarios such as rainfall and contigent events arising from environmental change.

4-6P: Extracting DOC dynamics using a newly developed Multiple State Dependent Parameter Model (MSDP) applied to synchronous streamflow and temperature data

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This study investigates the dynamics of Dissolved Organic Carbon (DOC) using a Multiple State Dependent Parameter (MSDP) models based on a rainfall-driven transfer functions with state dependent parameters. The SDPs are further conditioned by time-series of both streamflow (an expression of the dominant runoff pathways) and temperature (an additional meteorological control affecting biological processes). The MSDP modelling was undertaken within a Data-Based Mechanistic modelling (DBM) framework to permit new understanding of the processes governing dynamics observable within stream DOC concentrations. It was derived directly from several months of high frequency (every 15 minutes) observations of rainfall, streamflow, temperature and stream DOC concentration (via *in situ* UV-Vis spectroscopy) monitored in four adjacent basins. These are Lancaster-maintained experimental basins near to the Llyn Brianne reservoir in SW Wales and form the core research area of the ongoing NERC DURESS project. The accuracy of the particular MSDP approach presented benefited from a new development within the MSDP algorithm, which now fully accommodates the variation of parameter-driving states. The simulation efficiency and mechanistic interpretations of the derived MSDP models derived were evaluated against findings from: (1) a rainfall-DOC model based upon a transfer function model with fixed coefficients and (2) a similar model but with a single SDP derived solely from the rainfall time-series. MSDP has considerable potential for application to the study of other water quality variables affected by a wide range of environmental changes.

4-7P: The influence of forest harvesting on stream temperatures.

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There is increasing interest in the use of riparian woodland to mitigate high stream temperatures under climate change. In North America, much previous research has focussed on understanding the effects of forest harvesting, primarily because of the negative impacts on maximum stream temperatures and the consequences for salmonids. These two research areas can be considered complimentary, since changes in temperature observed during forest harvesting are likely to be similar in magnitude to the converse situation of riparian planting. In both of the aforementioned contexts there is a requirement to estimate (with confidence) the stream temperature changes associated with changes in riparian cover. This paper presents the findings of a study that assessed stream temperature changes associated with forest harvesting in Scotland using a series of Before–After–Control–Impact (BACI) experiments. The objectives of the study were to (1) investigate the potential of functional data analysis (FDA) methods to quantify changes in stream temperature associated with changes in forest cover (2) determine the magnitude of temperature changes associated with routine forest harvesting in the UK (3) determine the importance of landscape and forestry effects on the magnitude of observed temperature responses. FDA allowed a concise analysis of daily temperature signals not possible with previous analyses of summary metrics. The magnitude of felling effects was related to the spatial extent of felling, and channel orientation. The impacts of felling were generally short lived (< 5 years), potentially reflecting growth of understory in the riparian zone of the low order study streams.

4-8P: Identify the dominant hydrodynamic characteristics of horizontal mixing in a shallow lake: Numerical simulation of the transport process of waterborne material in Tai Lake, China

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Tai lake (in south of China) has experienced dramatic water quality degradation associated with rapid land development and the developing economy. The water quality is poor and 3 northern bays suffer from annual algal blooms, which increase cost of water purification. Tai lake has heavily polluted because of the eutrophication and about 800 sq. km is covered with fast-growing and foul-smelling green plant. The event of blue green algae outbreak in 2007 caused enormous losses, hundreds of thousands people's water security were seriously affected. Although every year, a large amount of Yangtze River was channelled into the lake to dilute the pollution, the water pollution indicators remained high.

The horizontal mixing properties of the flow in Tai lake will be mainly investigated by the application of chaotic mixing. The most important advantage of chaotic mixing is to describe the mixing process of each inflow which contains domestic sewage and agriculture pollution with the lake and point out which inflows are the ones mixing very well with the lake. These inflows will have greater influence on the water property than those poor mixing ones. This makes it possible to preventing the pollutions going into the lake by controlling those inflows having strong mixing ability. Also, inflows/outflows induced chaotic advection has the ability to enhance the mixing and transport properties of the whole lake, which can make sure that fresh water could approach everywhere around the lake.