Indo-UK Workshop Report on Water Quality – Source Protection

Jointly organised by James Hutton Institute, Scotland
& Interdisciplinary Centre for Water Research, Indian Institute of Science

Bangalore
30th March 2016 to 1st April 2016
Golden Jubilee Hall
Dept of Civil Engineering, IISc.

Preface

This report summaries the discussion and outputs of the Indo-UK workshop held at the Indian Institute of Science, Bangalore between the 30th of March and the 1st of April 2016. This report is intended for use by the participants of the workshop and other relevant stakeholders interested in developing a research and technology transfer agenda focused on water security issues in India. The report has been authored by Dr Richard Allan of the James Hutton Institute with input from other participants of the workshop.

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Acknowledgements

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Executive Summary

In March 2016 the James Hutton Institute in partnership with the Indian Institute of Science and the Centre for Ecology and Hydrology; supported by the Scottish Government; delivered a workshop which explored real-world opportunities for research collaborations focused on water source protection. This workshop was part of an ongoing series of initiatives between the UK and India designed to strengthen knowledge sharing in water management and deliver world class policy led science and engineering that addresses international challenges as set out in the Sustainable Development Goals.

The three day workshop hosted at the Indian Institute of Science, Bangalore was attended by 24 leaders in water science research and policy from India and the UK. The workshop achieved its objectives to develop a common understanding of the challenges relating to water source protection. The links and themes developed through the workshop have crystallised thinking around a range or strategically important research areas which will be further developed into deliverable projects to be initiated in 2016. Common themes included:

1. Modelling nitrate in groundwater
2. Development of a rural modular wastewater treatment system
3. Holistic and integrated community engagement
4. National, regional and catchment scale monitoring and evaluation
5. Development of the national regulatory laboratory capability
6. Adaption and adoption of a Hydro Nation philosophy to resource management
7. Development of innovation through support of young entrepreneurs

In order to maintain momentum and capitalise on the emerging issues, three project areas were identified for immediate support:

- Development of the modelling of nitrates in groundwater
- Development of a demonstration modular wastewater treatment system
- Development of a workshop(s) to promote and support improvements to India`s analytical laboratory capabilities.

Overall, there was strong consensus that there was a need for excellence in science delivered through partnership between India and the UK that underpins and informs policy making. The MOAs established between the Indian Institute of Science and the Centre for Ecology & Hydrology and the James Hutton Institute support this collaboration, as does the recently awarded Newton Bhabha fund project "Upscaling Processes for a Sustainable Cauvery: Hydrologic Analysis and Policy Evaluation". There was however, much discussion on further research and technology exchange between the two countries to meet the challenge of addressing the Sustainable Development Goals for water, energy, land use and communities.

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Introduction

The strategic workshop brought together leading freshwater and terrestrial scientists from across India and the United Kingdom and explored future scientific and technology needs together with challenges which underpin the sustainable management of water resources in India. The workshop developed ideas for future scientific and technological collaborations between the UK and India that will address key knowledge gaps in our understanding of water resources management and source protection. During the planned 3 day workshop the group were particularly focused on water quality and water source protection. There is recognition that there is a significant hydro climatic variation across India and there is a need to define monitoring and quality standards that can accommodate such variation while ensuring that water quality and quantity is adequately safeguarded.

The visit was coordinated by the James Hutton Institute and supported by the Scottish Government and in collaboration with the Indian Institute of Science and the Centre of Ecology and Hydrology.

Background

The UN Sustainable Development Goal 6 "Ensure access to water and sanitation for all" recognises the right of citizens to access safe water and sanitation. Water scarcity, poor water quality and inadequate sanitation have a measurable negative impact on energy and food security. By 2050 it is predicted that one in four people are likely to live in a country affected by chronic or reoccurring shortages of water.

Within the global context, India has a population of 1.2 billion with a growing global economy but also faces high variability in water availability with an over-exploitation of resources, such that the country is facing emerging water resource and quality issues. Under current predictions of monsoonal variability and other hydro-climatic events it is anticipated that the problem of water availability for users will worsen into the future. Over-exploitation of groundwater for agriculture (supported by subsidised power supplied from the State) has resulted in decreasing water-tables and loss of resource. Water use efficiencies are also sub-optimal and interventions to improve water use efficiency in agriculture are urgently needed. In many locations the shift towards water-intensive high value agricultural, and particularly horticultural crops, has exacerbated the problem.

Food, water, energy security and ultimately resource efficiency (and the circular economy principles) represent an interlinked and increasingly important factor in sustainability with presently about 80% of abstracted water being used in irrigated agriculture which also consumes approximately 30% of total Indian energy. A growing urban population with associated industrialisation is rapidly increasing the water demands of towns and cities such that many urban areas are facing severe water-shortages, poor peri-urban potable quality

and associated health concerns. Further, the untreated discharge of wastewater is impacting both surface and groundwater in many regions of the country.

Water management is an area of UK commercial and policy expertise and the Scottish Governments Hydro Nation Agenda further develops a focus for water expertise through a range of supporting activities delivered by the Centre of Expertise for Waters (CREW), the Hydro Nation Water Innovation Service (HNWiS) and the Hydro Nation Scholars Programme. A UK mission to India in March 2015 identified potential areas of collaboration in governance and regulation, potential ongoing science and innovation links and significant opportunities for India-UK engagement in the water sector. The UK has many skills in these areas, not least due to similarity of its administrative and legal systems. Water planning and protection capability in the UK has resulted in significant improvements in water quality and water security, and strengthening India-UK links in this area is considered likely to bring significant benefits to India and opportunities for partnership with the UK water sector. The discussion at the workshop resulted in the further development of two related workshops, one focusing specifically on the Ganga and supporting Prime Minister Modi`s ambition to clean-up the Ganga under the National Mission for Clean Ganga (NMCG). The Ganga Workshop was held in the UK in November 2015. A second workshop was identified to focus on the priorities around water source protection and this report covers the output of that workshop which was held between the 30th of March and the 1st of April 2016.

Participants

The workshop was attended by 11 representatives from the UK and a further 13 from India, the delegation comprised of:

Table 1: List of delegates attending the Indo-UK Workshop March 2016.

Name	Institution
Professor Bob Ferrier	The James Hutton Institute
Dr Richard Allan	The James Hutton Institute
Dr Mads Troldborg	The James Hutton Institute
Dr Alison Parker	Cranfield University
Mr Barry Greig	The Scottish Government
Professor Alan Jenkins	Centre for Ecology and Hydrology
Professor Mark Bailey	Centre for Ecology and Hydrology
Professor Edward Tipping	Centre for Ecology and Hydrology
Dr Harry Dixon	Centre for Ecology and Hydrology
Dr Andrew McKenzie	British Geological Survey
Professor Graham Mills	Portsmouth University
Professor Pradeep Mujumdar	Indian Institute of Science
Professor Sekhar Muddu	Indian Institute of Science
Professor M. Sudhakar Rao	Indian Institute of Science
Professor M.S. Mohan Kumar	Indian Institute of Science
Dr. Laurent Ruiz	Indian Institute of Science
Professor Ligy Philip	Indian Institute of Technology
Professor Sudha Goel	Indian Institute of Technology
Professor Chakrapani Govind	Indian Institute of Technology
Dr Arun Kumar	Indian Institute of Technology
Mr Sunil Kumar	UK Science and Innovation Network
Mr Rajesh Parishwad	The Royal Society of Chemistry
Mrs Deeksha Gupta	The Royal Society of Chemistry

Workshop Programme

Over the three days of the workshop there were a range of presentations and discussion principally focused on water source protection. During the course of the discussion the delegates were asked to consider a range of strategic questions that helped identify a number of tangible outputs and research deliverables. These questions included:

1. How is the water supply demand balance changing across India? What are the influencing factors (for example, climate change, farming, urban creep, industrial change and economic growth)?

2. How is water quality changing? What are the main contributing factors that influence raw water quality deterioration?

3. What is the existing nutrient load (as N and P) within raw water and how does this impact on water quality, water security and the environment/ecosystem?

4. How does activity in the catchments influence and effect the raw water quality and security? Do we know enough about how such activities impact on water security, quality and ultimately the protection of public health?

5. What water quality monitoring programs are in place in India and the UK? What are the similarities and differences? Where are the knowledge gaps in terms of understanding the water quality and the source of contaminants?

6.What coverage of wastewater treatment is in place? How can improvements in wastewater treatment at a local and national level safeguard raw water sources?

7. What management practises are in place to address diffuse pollution issues? What modelling needs to be done and to what scale (Catchment and or farm scale)?

8. What are the consequences for future land management and ecosystem services?

9. How can the sustainable rural community approach support local resource management?

By exploring these questions and others, the workshop identified strategic challenges for water management research in India over the next 10, 20 and 30 years. Delegates considered the feasibility of meeting such scientific priorities and, in particular, what was needed to enable the required research. The following sections discuss the topic specific output from each session.

Understanding Water Quality

Professor Sekhar Muddu and Professor Bob Ferrier opened the workshop by welcoming the delegation and giving an overview of the event. The session was then chaired by Professor Alan Jenkins and presentations were given on understanding water quality and more specifically on some of the overarching water quality issues in India.

Professor Bob Ferrier gave a compelling overview of the considerations for understanding water quality within the global context. The presentation covered high level insights into the magnitude of water quality issues; the impact of human activity on water quality; considerations for research and policy in water that informs critical areas such as monitoring, infrastructure and innovation designed to protect and improve water quality.

Figure 1: Professor Alan Jenkins and Professor Bob Ferrier discussing *"Understanding Water Quality"*

Professor Sudha Goel then gave a very comprehensive and informative overview of the challenges of water quality protection specific to India. Professor Goel highlighted the shift from predominantly river abstraction to groundwater. In terms of water use, it was highlighted that some 90% of water in India is abstracted for irrigation with around 62% of this water now being abstracted as ground water. The move from surface water to ground water has changed the hydrology and Professor Goel highlighted the lack of water quality monitoring of ground water which, in many cases, was known to contain contamination potentially harmful to human health and the environment. Furthermore Professor Goel discussed priority pollutants and the need to change water quality standards and regulation to drive the right behaviours required for water source protection. Finally Professor Goel stressed the need to agree standard analytical methods for water quality monitoring and a national program for water quality surveillance. Figure 2, taken from Prof Ferrier`s presentation provides insights into the scale of the challenge for water quality management in India.

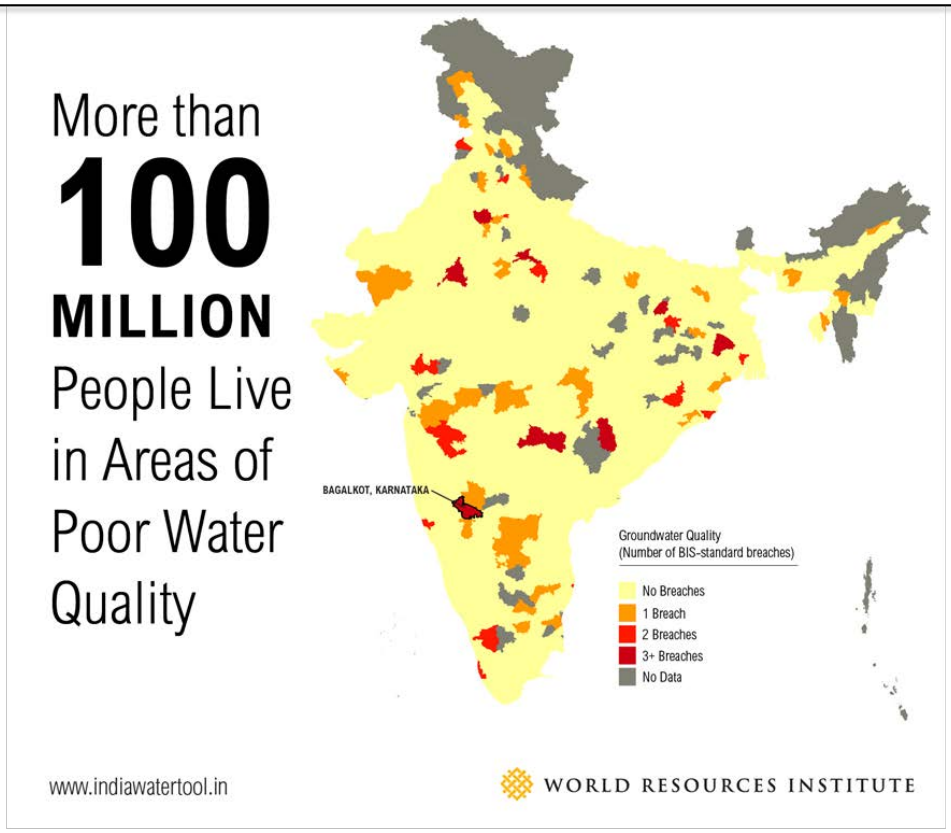

Figure 2: The Scale of the Challenge

The session highlighted significant challenges and provided an excellent framework and reference point for the workshop. The strategic challenges set out by Professor Ferrier and Professor Goel can be summarised as:

- Water source protection is imperative to public health, the environment and economic prosperity.
- Water quality underpins all human and environmental activity.
- Water source protection requires changes in approach to;
    - Regulation,
    - Innovation and best practise,
    - Community engagement.

Water Quality

The second session of the workshop explored the need to evaluate, monitor and protect water quality and was chaired by Professor Edward Tipping of The Centre for Ecology & Hydrology. There were two presentations by Professor Alan Jenkins, who explored the UK approach to understanding the surface water flows in the UK and the lessons learned from harmonising the monitoring schemes. This was followed by a presentation by Professor Graham Mills, who highlighted the advances in passive sampling and the value that this low cost option can bring to water quality monitoring. The session highlighted:

Session 1: Water Quality

- National (or jurisdiction) water quality standards are desirable.
- There is an opportunity to develop Indian national standard methods for monitoring chemical and biological parameters.
- There is an opportunity for a collaborative project to provide training in analytical techniques for Indian regulatory laboratories.
- A National (or jurisdiction) monitoring program based on a risk assessment approach is desirable.
- Research Proposal: there could be a demonstration project to identify top chemicals of interest and run pilot to assess what understanding can be developed given different modelling frameworks.

During his presentation, Professor Jenkins highlighted that water quality data is of critical importance and must be linked to flow data to be meaningful. This means that the data needs to be defendable and must have adequate quality controls and assurance around sampling and analysis. The data must also be generated at an appropriate frequency to be able to support the models and assumptions made about the models. Professor Jenkins concluded that we cannot be complacent in our pursuit of water quality protection and so we must continue on the journey of understanding the ecological thresholds, the emerging contaminants and the cost of compliance; all of which will inform appropriate management options.

Professor Mills then followed on by discussing the European regulations (in the form of the Water Framework Directive (WFD)) and explained how this influenced the monitoring strategies of the European member states. Professor Mills discussed the traditional method of "spot sampling" and the fact that this only provides a snapshot of a water body dynamics that is not necessarily representative of the continuous conditions of the water system. He went on to explain that passive sampling can give a different insight into the concentrations of parameters in water bodies by providing a time weighted average.

The workshop participants agreed that passive sampling had a potential role to play in an integrated monitoring strategy for India. The passive sampling activity could inform a risk assessment which would then drive a more targeted monitoring and management plan for delivering water source protection.

Diffuse Pollution Assessment

The second day of the workshop opened with a welcome from Professor Pradeep Mujumdar who also chaired the first session of the morning. This session focused on diffuse pollution assessment. Overall the workshop group highlighted this topic area as one of importance particularly when considering national scale nutrient management. The workshop group highlighted several strategically important areas for collaborative research:

Session 2: Diffuse Pollution assessment

- Carbon, nitrogen and phosphorus budgets need to be established over a range of spatial and temporal scales. This can be achieved through modelling and limnology.
- Standards and policy setting environmental nutrient limits need to be harmonised across the jurisdictions of India.
- The nutrient budgets should be developed in a way to make them scalable and relevant to site specific standards, where they exist.
- The application of low cost sensing systems would be desirable to validate the modelling activity.

Professor Edward Tipping of the Centre for Ecology & Hydrology opened the presentation session with an informative look at the links between biogeochemical cycles and water quality. The core theme of the presentation was based on *"Long term/Large scale"*(LTLS) interactions of carbon, phosphorus and nitrogen in the UK land, freshwater and atmosphere domains (Figure 3). Prof. Tipping highlighted that an integrated modelling approach is successful; the process times vary from days to centuries as there is a need for a long term perspective; and the environment is a very noisy place so there is a limit with the driving data which informs average behaviour.

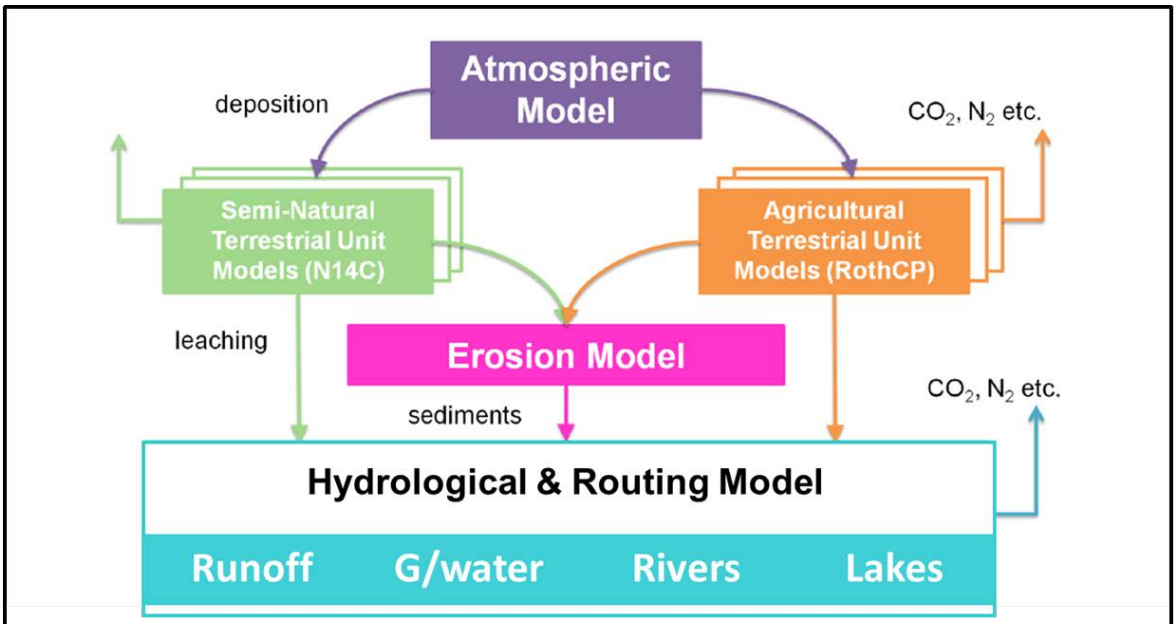

Figure 3: Long Term/ Large Scale activities

The next presentation was a detailed case study on the biogeochemistry of the Kumaun Himalayan Lakes presented by Professor Govind Chakrapani of the Indian Institute of Science, Bangalore. His presentation highlighted the changes to the surface water in lakes from 1960 to 2010 (Figure 4). Professor Chakrapani suggested that the lakes could be considered as a natural laboratory where there has been a measurable impact on the lake system from human activity. The research team have observed that the increases in development have caused rapid sedimentation and pollution which contributed to eutrophication. The detailed work of Professor Chakrapani and his colleagues had identified a number of conclusions that include:

- C/N ratio, n-alkanes, TAR, CPI and nitrogen isotopic values show that organic matter in these lakes are primarily dominated with in-lake algal production.
- Elemental carbon concentration indicated lake productivity has been increasing.
- Total sulphur in Nanital and Bhimtal is very high and represents higher reduction rates. The lakes are anoxic and degradation of metabolisable organic matter due to sulphate reduction leads to sulfur isotopic fractionation.
- Stable carbon isotopes represent influence of DIC from sewage input and cycling of lighter carbon by methanogenesis under anoxic degradation of organic matter.

- Stable nitrogen isotopes indicate atmospheric nitrogen fixation by cyanobacteria and denitrification process in sediments.
- Dominance of cyanobacterial pigments like zeaxanthin and echinenone imply nutrient limitation and atmospheric nitrogen fixation, and reflects increase in the incorporation of lighter isotopes in sediments

Figure 4: Changes to the biogeochemistry of the Kumaun Himalayan Lakes between 1960 and 2010.

It was felt that the control of contributing factors of eutrophication and reversing the effects was a priority and there was an opportunity for some collaborative research in this area.

Managing Diffuse Pollution

The 3rd session of the workshop, chaired by Professor Graham Mills, centred on debating affirmative action and leadership in managing diffuse pollution. There were three presentations in this session focussing on modelling and monitoring of ground water; pollutant modelling of ground water; and a case study examining the work conducted in the Kabini basin. The priorities highlighted through the discussion included:

Session 3: Managing diffuse Pollution – Options for collaboration.

- India has the opportunity to focus on drinking water quality in addition to environmental modelling.
- There are many opportunities and perhaps a strong initial candidate is nitrate modelling. This should be promoted as one of the quick win projects.
- The modelling will need to consider such elements as what existing data is available, what resolution is appropriate, what are the acceptable uncertainties?

The initial presentation of the session was given by Dr Andrew McKenzie, who set out the drivers for monitoring in a European context where there was a need to demonstrate compliance with EU directives such as WFD. Monitoring can also be set up to support investigative work, perhaps be used for defensive purposes and, importantly used to inform strategic decision making. Dr McKenzie went on to explain the UK strategy for monitoring and discussed the guiding principles, the range of parameters selected, and the interpretation of the results. Dr McKenzie then discussed how the monitoring data was used in concert with modelling the behaviour of selected parameters in relation to groundwater.

Dr Mads Troldborg followed with a comprehensive presentation on groundwater pollutant modelling which discussed the drivers for modelling, the challenges and uncertainties and then presented some illustrative examples of applying a modelling approach. The presentation highlighted the importance of considering data, scalability of the model, the conceptualization of the groundwater systems and the uncertainty analysis.

Professor Sekhar Muddu finished the session with and very informative presentation on his work in the Kabini basin (Figure 5) which is located South and West of Bangalore. Figure 5 shows the size and extent of the river basin district together with some of the sub-areas used in the innovative research projects conducted by Professor Muddu and his team. The work conducted to date employs a range of modelling techniques and methodologies used in concert with data collected form a number of strategically placed montioring systems that include Eddy flux towers, COSMOS systems and Hydra probes. In conducting this valuable research Prof. Muddu has been able to build a comprehensive picture of the hydrological functioning of the Kabini basin.

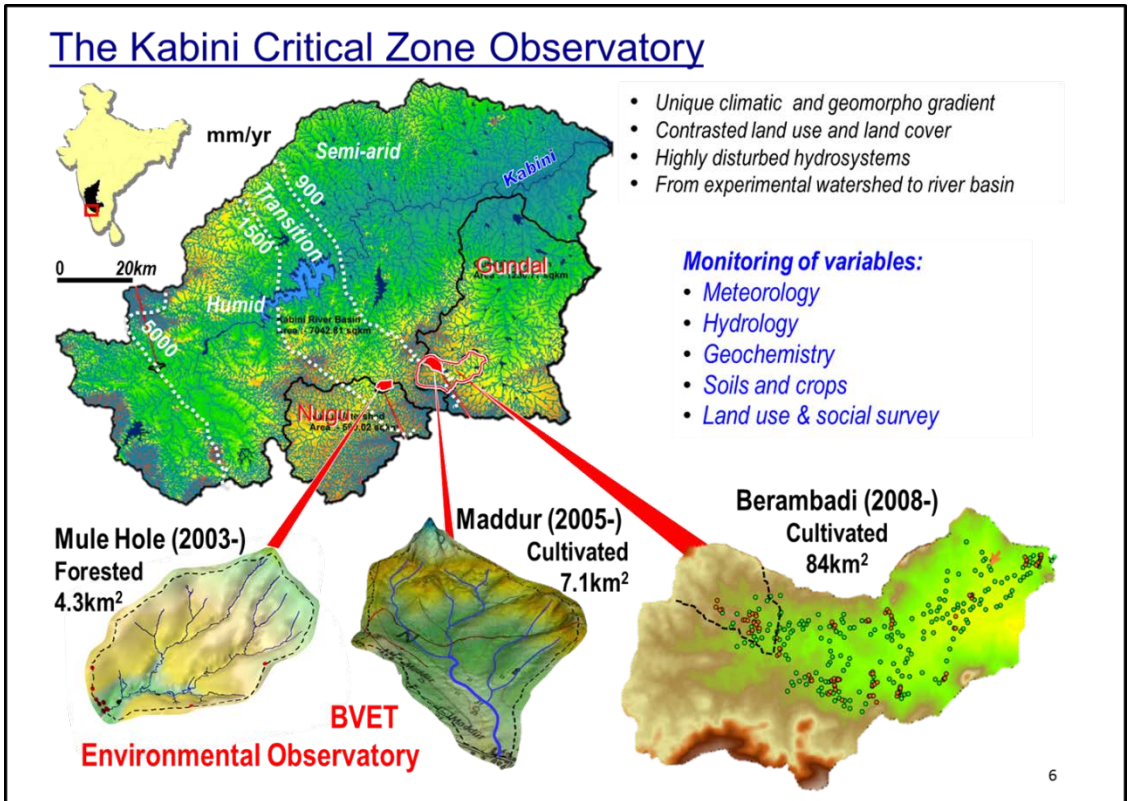

Figure 5: The Kabini Basin

Overall the session highlighted a range of excellent science that will inform water management policy in the UK, Europe and India. The discussions highlighted the need to continue the work and perhaps focus on specific issues such as nutrient modelling. A compelling case emerged around research into nitrate transport and fate modelling in groundwaters. This was identified as a priority for a joint collaborative project between the UK and India, and partners would seek support to move this forward in the short term.

Figure 6: Prof Muddu presenting on his work in the Kabini Basin.

Sustainable Rural Communities (SRC)

The fourth session of the workshop changed focus from catchment scale modelling to consider rural communities and managing water source protection at a local level. The session was chaired by Professor Bob Ferrier and the opportunities for research emerged as:

Session 4: Sustainable rural communities

- There is scope to cooperate on small rural water and wastewater treatment systems as parallels between rural communities in the UK and India were identified (use of borehole water supplies, septic tanks, etc).
- Community engagement is strategically important and there is an opportunity here to build both social engagement and agro-economics into a community pilot project.
- Nitrate contamination is a common theme and further supports the proposals to develop a nitrate modelling project.
- The SRC concept could help support understanding local dimension and engagement is critical to success given diversity of local practice – related challenge of understanding & navigating relationship and responsibilities of layers of government could be considered.

The session opened with a presentation by Dr Richard Allan, who highlighted the SRC agenda within Scotland and led by the Centre of Expertise for Water (CREW). The program of projects contributing to the SRC agenda was co-constructed by a range of policy stakeholders, academics and industrial partners. The initiative is designed to put the community at the heart of the research and address a number of underpinning strategic areas (Figure 7) that include, managing the resources (resource efficiency) where it is recognised that rural communities may be remote and have limited access to resources; regulation to help protect the environment and public health; innovation to support low cost efficient water and wastewater treatment; and engagement with the community to ensure buy in for any proposed improvements to the systems, processes or services.

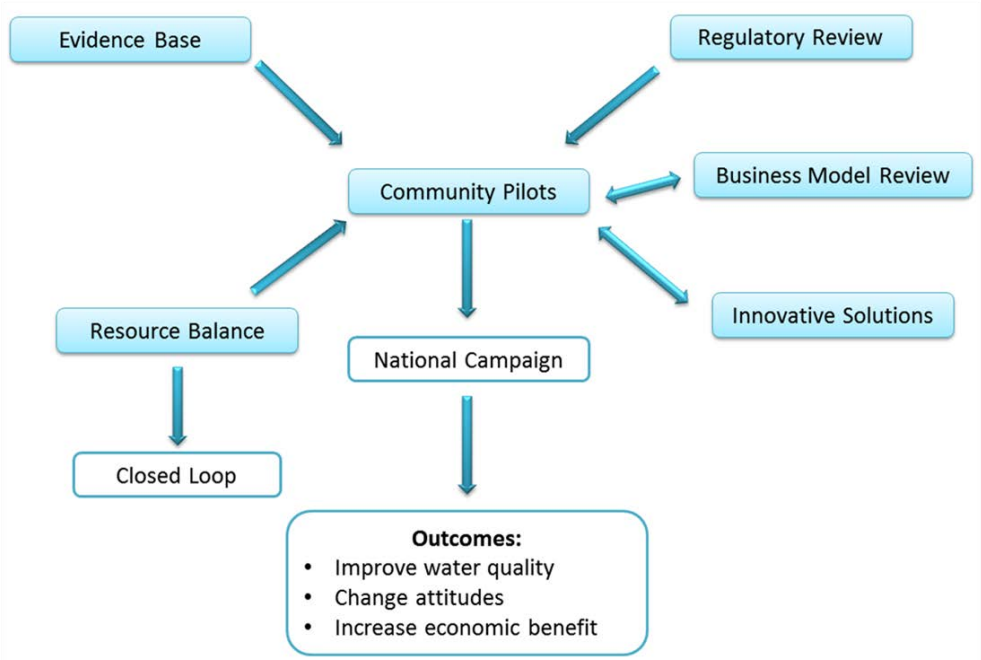

Figure 7: A Holistic Approach to Sustainable Rural Communities

The output of the SRC program to-date has been encouraging with the development of a low cost wastewater treatment system (Dinnet); the delivery of an innovation assessment model; the production of a risk management tool based on a quantitative microbiological risk assessment approach and the current activity with embedded researchers in a number of study catchment areas within Scotland. There is scope to adapt this approach for rural community studies in India.

Professor Arun Kumar took the delegation through the work being conducted on assessing the impacts on water quality in rivers from activities related to hydropower, construction and other water related projects. Professor Kumar observed that structures, such as hydro-dams alter the water regime downstream and this needs to be factored in and understood when considering the design and construction of projects. Importantly the trade-offs between energy security, growth and impact on the environment and local population need to be understood. In many of the examples presented, it was shown that water quality deterioration was attributable to construction of civil structure and one of the most significant impacts on changes to water quality was solids (mud/muck) disposal. Prof Kumar pointed to activities such as road construction, dam construction and urbanisation as sources of soil waste. This soil waste disposal was not adequately governed.

Case studies in Alaknanda, Bhagirathi, Yamuna and Sutlej Basins were used to illustrate the findings of the research. Professor Kumar concluded by re-enforcing the message that civil structure on or near the water bodies will alter downstream water quality and ecosystems. There is a real need to improve governance for construction waste disposal. Consideration also needs to be given to managing the impact of natural landslides and there is a pressing need to ensure treatment of wastewater due to anthropogenic activities. There is scope here for collaborative work to identify best practise in construction management and governance.

Figure 8: Professor Kumar (Indian Institute of Technology) giving a lecture on the impact of Hydro-schemes on water quality.

The session was concluded with a presentation from Dr Laurent Ruiz (IISc, Bangalore) who gave a very comprehensive and insightful lecture on the history of agriculture in India and the impact this has had in terms of water resources and diffuse pollution. Figure 9 shows the changes in crop production across India between 1960 and circa 2010.

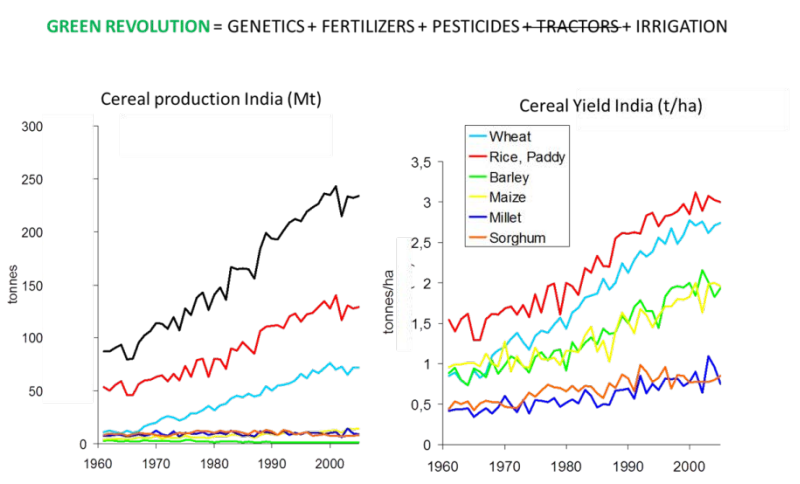

Figure 9: Changes in Agricultural out-put in India from 1960 to 2010

The figure shows the changes in agricultural practices during the "green revolution" and the significant changes to the output in the last 50 years. Dr Ruiz then went on to describe the impact that these changes have had on the environment and water across India and specifically in the three study site (Pune, Goa and Bangalore). Dr Ruiz explained the work being conducted under the AICHA project which aims to study the agrarian and environmental crisis in a groundwater dependent catchment using the Kabini sub-basin of the Cauvery basin as the case study. The research aimed to develop a comprehensive framework of analysis to understand the role of agronomic and water management, under the changing forces of climate, markets and agricultural policies. The research provides a framework describing farmers' behaviour and their strategies by collaboration between researchers seeking to understand the social-economic hierarchies and biophysical asymmetries of resource availability within the watershed, spatially and temporally; and test alternative policy scenarios to achieve sustainable outcomes at the household-level, at regional agricultural production level, and to achieve sustainable environmental outcomes. Dr Ruiz concluded by highlighting that the work is ongoing and entering a critical phase with additional soil monitoring eing undertaken to better understand the soil organic matter mineralization, crop production variability and the contined impact on ground water resource quality and quantity.

Low Cost Treatment and Waste Management

Day two of the workshop was concluded with a session on low cost treatment and waste management. The session was chaired by Dr McKenzie (The British Geological Society) and the notable emerging themes for action included:

Session 5: Low cost treatment and waste management

- Cross contamination of wells appears to be a factor and research into the impact of this is desirable.
- There is a notable significant number of discharges from industrial sources and this needs attention at a national level. Research into governance and regulation of waste treatment in discharge is recommended.
- The theme of monitoring was revisited. There is a clear emerging need to establish national standards across a full range of parameters. This needs to be supported by adequate training for regulatory laboratories.
- There is a need to establish pilot demonstrations for low cost, energy efficient sustainable treatment.

Dr Parker from Cranfield University opened the debate on water treatment by discussing her work in Africa which focused on point source protection in rural areas with limited resources. The lessons learned from her research are applicable to many similar situations internationally. Dr Parker explained the typical borehole construction and highlighted some of the risk considerations when thinking about securing safe water. Figure 10 gives some examples of wells and source types in the case study catchment in Uganda. The research highlighted that there are many considerations when considering appropriate technology for rural communities and a significant factor is cultural acceptance of innovation. This was a theme highlighted in Dr Allan`s presentation on SRC and in Dr Ruiz presentation on changing agricultural practises.

Figure 10: Example source types in Uganda

Dr Parker pointed out that hand dug wells (ring wells) were largely a communal responsibility and encouraged good environmental behaviour. Then there was a change with the government promoting handpumps on boreholes, which are owned by an individual and were often poorly constructed and lacking in sanitary seal or apron, meaning a greater risk to public health. However, households liked them as the low lift handpumps (chakapals) are cheap and it takes less time to collect water from near to the house. So while the community systems were better for public health the individuals preferred their own systems, even though the risks were higher. Dr Parker concluded by observing:

- Properly protected point sources can give good quality water, eliminating the need for further treatment
- There is a need to eliminate open defecation whilst not contaminating groundwater
- There is a need to consider social and cultural needs

The second presentation of the session was given by Dr Priyanka Jamwal who gave a very compelling lecture on the management of industrial discharges in the river systems in India. Dr Jamwal highlighted the need for strengthened regulation and a national approach to setting discharge consents, parameter selection, monitoring strategies and subsequent enforcement action where identified. This was consistent with both Prof Goel and Prof Kumar`s observations. The significant re-occurring theme here was the need to agree on regulatory analytical methods and to up-skill the laboratories undertaking such testing to ensure comparability of data. Generation of a national data set based on standard methods will help to inform policy decisions for the regulation and control of industrial pollution and wastewater discharges into water bodies. There is a real opportunity here for a collaborative research agenda which delivers improvements to India`s analytical capabilities and regulatory framework.

The third session in the series was delivered by Professor Sudhakar Rao of IISc Bangalore, who shared his work on the prevention of nitrate contamination of groundwater in Mulbagal town through use of bio-barriers at pit-toilet locations. Professor Rao suggested that around 7737 households have pit-toilets for individual use in Mulbagal town. The population is 60,000 and the water supplied is circa 5 Ml/day and entirely through ground water. Majority of wells drilled between 2000 and 2005 to depths ranging from 16 to 70 m. Based on spatial distribution, wells in Mulbagal town classified as inner town series (ITS) drinking water wells (43 number) and pump-house series (PHS) wells (26 number) are located outside or the periphery of the town. Drinking water wells belonging to the PHS supply water to centralized municipal supply system where pumped water are collected in sumps; water from the sumps are pumped to service reservoirs which then supply water through piped network to individual households or community taps at street levels. In order to augment supply, drinking water wells were installed inside the town (belonging to the ITS); the water pumped from ITS wells directly feed into a separate localized pipe network that provide water to individual households/community taps/ small water tanks (approximately 1200 L capacity) in the vicinity of the well. The ground water was shown to have high levels of nitrate in some cases greater than 170mg/l compared with an expected Indian standard of 45mg/l in drinking water. There was a clear need to change the design and operation of the pit latrines to protect the groundwater source. This was achieved in the experimental sites by adopting a number of strategies that included:

- Developing a bio-barrier
- Denitrification using CM-sand mixes
- Re-designing the latrines
- Channelizing sullage flow to existing drain

The initial results appear to be promising with one well showing a nitrate level of 248mgl^{-1} before installation with the levels dropping off to <1mgl^{-1} nitrate at the surrounding sample points at the beginning of the experimental observation period.

The final session in this section was presented on Day 3 of the workshop by Professor Ligy Philips of IIT, Madras, who discussed her leading work on sustainable wastewater treatment system in rural India. Professor Philips reflected on the changes to the Indian population with and continuous increase and there is a trend for the population to migrate to the cities with around 25 to 30 citizens migrating to the urban centres every minute. By 2050 it is expected that some 843 million people

will inhabit Indian cities and so a smarter management of resources and facilities are essential. In rural areas there are challenges around wastewater management approaches to issues such as disposal of septage by vacuum trucks into uncontrolled open channels and open dumping of septage in low lying areas resulting in hazardous conditions and multiple exposure routes to faecal derived pathogens. Professor Philips highlighted that some 73 million working days are lost each year as a result of water borne disease which is estimated to cost the economy around $600m per annum. Around 6.4% of Indian GDP is lost due to improper sanitation and the impact on tourism is estimated at $448m per annum. There is a clear need to improve sanitation to enhance and improve public health which would ultimately support growth and economic stability.

Ideally, there would be a national approach to wastewater management but this is controlled by jurisdictions and often there are a range of limiting factors which include:

- Funding
- Power
- Trained staff
- Cost recovery (billing and tariff setting is not harmonised)
- Willingness to pay
- Community engagement and priorities

These existing challenges then prompt a debate about the types and scale of treatment that is appropriate for rural and urban settings. There are questions about the appropriateness of centralising or decentralising wastewater treatment systems coupled with consideration around onsite treatment with or without elements of recycling, nutrient recovery and energy recovery (and efficiency). Professor Philips then went onto describe the work at IIT to develop reliable and cost effective treatment technologies which are sustainable, socially acceptable and close the resource loop as far as possible.

Figure 11: Professor Ligy Philips of IIT Madras giving her lecture on sustainable waste management.

Professor Philips considered the flow and load of water within a single household to better understand the type of treatment that would deliver enhanced wastewater treatment at a low cost. Figure 12 is taken from her presentation and represents the flow and usage of water within a typical Indian household.

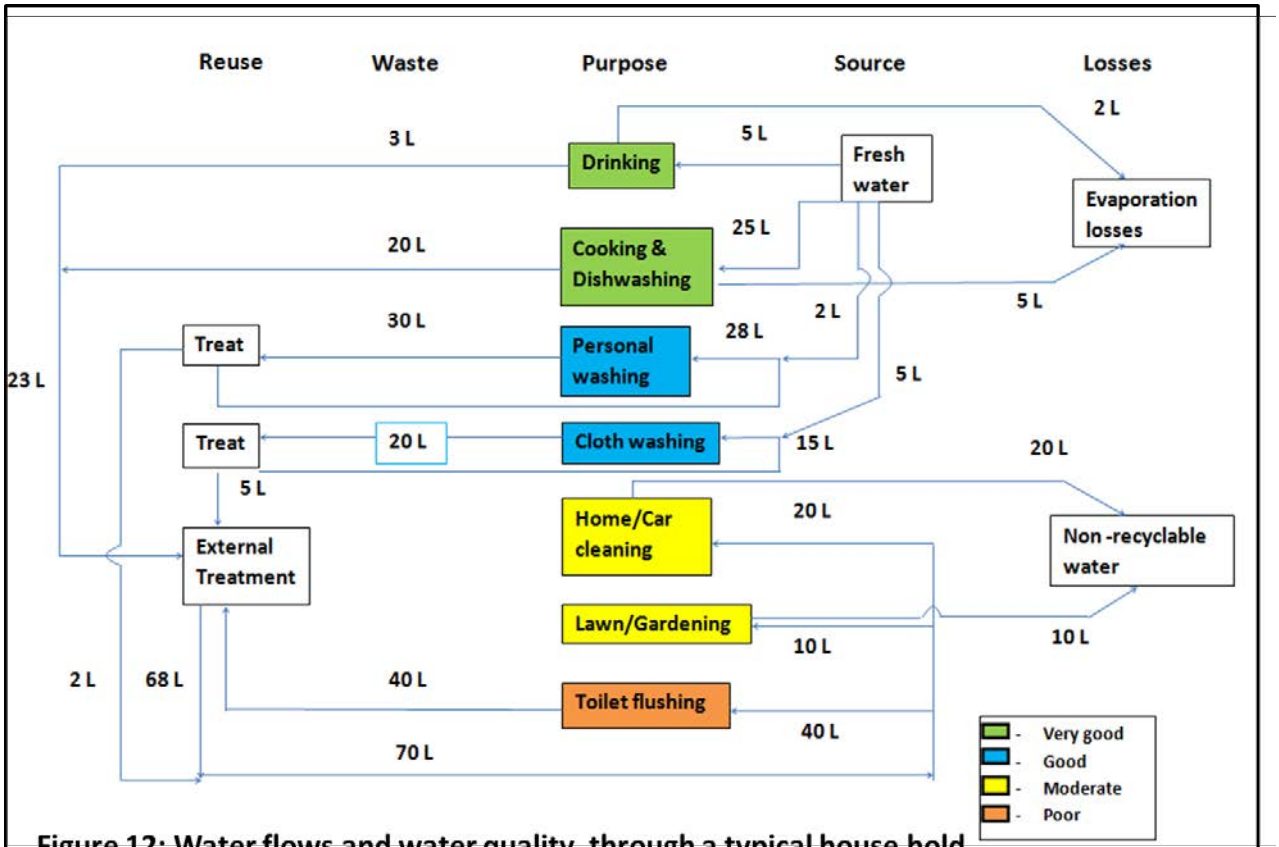

Figure 12: Water flows and water quality through a typical house hold

The water flow information and quality assumptions then informed the work undertaken to develop systems that both recycled water within the household system (for example washing machines) together with developing thinking around cost effective local treatment. Professor Philips and her team then went on to develop an integrated system that was modular and included:

- A modified septic tank
- An anaerobic baffle wall reactor
- An anaerobic attached growth reactor
- Pressure sand filter (or cloth filter)
- Constructed wetland

The laboratory scale modular system was then tested at a pilot site in Medavakkam, Chennai. The system was powered using solar panels and the process was optimised successfully with a measurable reduction in biological oxygen demand, chemical oxygen demand, total suspended solids and pH. The effluent was then discharged into a constructed wetland and the biomass could be used for energy production and or grazing for farm animals. More work is needed to understand the uptake of priority chemicals into the biomass and the implications of using in animal feeds. The initial results of the constructed wetland systems (both vertical and horizontal design) from 2014 show good performance. In conclusion, Professor Philips demonstrated that a modular decentralised wastewater system can be resource efficient and improve wastewater discharge quality; providing multiple benefits to the local rural communities.

Emerging Policy and Opportunities

The final session of the workshop was chaired by Professor Mohan Kumar of IISc, Bangalore and centred on the policy dimension of water management. There had been reference to the critical inter-dependency of the science-policy interface throughout the workshop and it is a golden thread which drives the research agenda; influencing water service providers and water users to more informed, sustainable practises. The emerging themes highlighted in the session included:

Session 6: Emerging policy and opportunities

- Good demonstration tests sites are needed in India to support demonstration of best practise.
- There is a need for affordable innovative technology to provide water and wastewater service.
- There is a need to support the translation of science into policy.
- There is a clear need to ensure policy supports sustainable water management.
- Water security issues are serious issues and are reflected in existing joint projects.
- Science and engineering is critical to informing policy.
- There is support for projects which inform policy and in particular supporting sustainable rural communities.
- There is a need to identify and adopt scalable solutions.
- Funding is available to support fundamental research into water security in terms of water quality and quantity.
- There is a need to develop affordable state of the art technical solutions and promote water reuse.
- There is an opportunity to develop governing stakeholder forums at state level similar to the HN Forum.
- More data is required to support policy led decisions.
- Need to increase the capacity for research in terms of skills (fellowships, studentships, etc).
- There is a need for a greater understanding of how policy can inform best practise water and wastewater management.
- There is an opportunity to bring young entrepreneurs together from UK and India to seek opportunities.

Barry Grieg of the Scottish Government presented the "Hydro Nation" agenda which is a multi-dimensional approach to water management in Scotland. The initiative considers a range of factors required for sustainable water management. These include:

- Increasing expertise – through the Hydro Nation Scholars program
- Increasing Innovation – through the "The Power of Youth" and the Hydro Nation Water Innovation Service.
- Delivering science informing policy – through the Centre of Expertise for Water (CREW)

Figure 13 depicts the range of water related policy initiatives in Scotland that support the Hydro Nation Agenda.

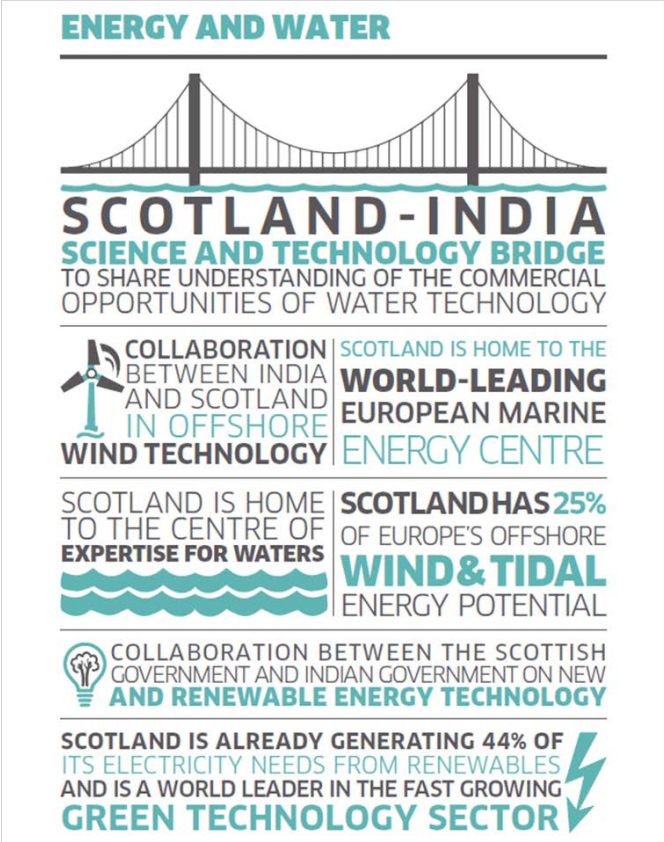

Figure 13: Policy related activity for Water in Scotland.

Mr Grieg went on to emphasise the importance of collaboration between policy makers, researchers and industry in order to deliver real transformational benefits. Mr Grieg stressed the importance of community engagement and involvement when it comes to developing local solutions to water management and associated services such as energy generation, agriculture, the protection of public health and social justice. Mr Grieg concluded by stressing the importance that the Scottish Government are putting on supporting the development of researchers and innovators for the future. This is very much at the heart of the Hydro Nation agenda and is driven through the Hydro Nation Scholars program with a current cohort of 16 PhD students together with the developing "Power of Youth" Program which is designed to support young entrepreneurs succeeding in bringing new technology to market and addressing global challenges.

Conclusions and Recommendations

The three day workshop at IISc, Bangalore achieved its objectives in identifying a range of challenges relating to water source protection and, importantly, recognised a range of opportunities for collaborative research which could address the local, regional, national and international priorities. The emerging research agenda is also very much aligned to the Sustainable Development Goals and in particular Goal No 6 "Ensure availability and sustainable management of water and sanitation for all". Through the course of the three days there were a number of themes identified which support existing thinking around the benefits to the science-policy interface and re-enforced the benefits of a strengthening India-UK collaboration. The strategic themes included:

Conclusions and Recommendations:

- Scientific collaboration between India and the UK provides a platform for policy led research which is a vital component of securing water source protection.
- There is a clear need to support the development of an integrated national approach to water quality monitoring. This includes upskilling laboratories; identifying appropriate parameters; setting national limits; implementation along with a developing agenda of water quality improvement through catchment management principles.
- Nitrate modelling is a specific emerging need at a regional and national level and should build on the Indian research based in the study catchments.
- Demonstration sites for low cost resource efficient water and wastewater treatment is recommended.
- Consideration should be given to developing an integrated approach to sustainable rural communities which very much includes engagement with the communities and economic impacts.

The workshop comprehensively considered all aspects of water source protection in both the UK and India and explored national modelling, ground water, surface waters, local and regional challenges, governance, treatment and monitoring strategies. Figure 14 highlights the main themes that were discussed during the course of the workshop.

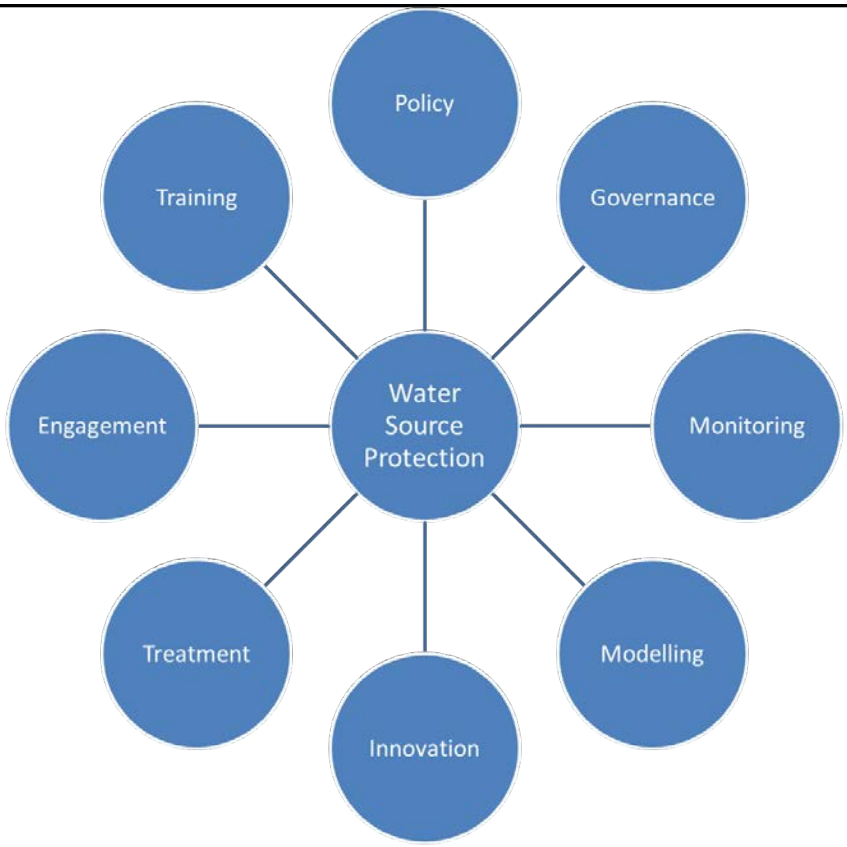

Figure 14: Emerging components required to support water source protection

While there is clearly scope for a range of activities and research opportunities, it was agreed that a number of priority areas should be identified through which to address merging societal challenges associated with water quality and to maintain momentum with India-UK research collaboration. The top three proposed projects to be scoped out and delivered in 2016 were:

1. Development of ground water transport and fate modelling of nitrate. The importance and impact of nitrate in the environment and their agricultural sources and loss was highlighted by many speakers. It has been agreed to establish a project between IISc, the Centre for Ecology and Hydrology, and the James Hutton Institute to benchmark models with the ultimate aim of informing policy making nationally and regionally.
2. Establish a demonstration of decentralised modular wastewater treatment. There is a clear need to identify and pilot a range of novel innovative modular wastewater treatment systems that address rural access to safe sanitation. With that in mind it is proposed to develop a pilot study in the Kabini catchment which will design, build and tests a modular system for decentralised wastewater treatment systems. This project will inform systems thinking and support the Sustainable Development Goal No 6.
3. Capacity building for analytical capabilities in India. Many of the delegates made reference to the need for a more consistent approach to analysis and monitoring of the aquatic systems in India. While national standards do exist, it would be desirable to assess the effectiveness of implementation and the appropriateness of the selected parameters along with their associated regulatory limits. This should be supplemented by a series of laboratory based workshop and demonstrations of laboratory techniques. It may also be beneficial to establish an inter-laboratory testing scheme to help upskilling of laboratory staff.
4. Implementation of catchment management principles. Consideration should be given to evaluating frameworks such as the Water Framework Directive as a benchmark approach to environmental regulation, standard setting and implementation. This might benefit from the lessons learnt from implementation in the UK, and potential transposition of some key guiding principle into the wider Indian context.
5. Identification and application of social aspects of the water-food-energy nexus to enable benefits of resource efficiency and circular economy approaches for managing resources at a local level.

As well as the top three research priorities there were a range of other opportunities that could be developed in partnership over time. These included:

- Strategy for tariff setting and financial regulation;
- Community engagement strategies;
- Development of industrial pollution controls and regulation;
- Collaboration between the young entrepreneurs of Scotland, UK and India to address the water challenges through innovation.

As part of the next steps the partner organisations in India and the UK will work together to develop project proposals in the identified areas and set out plans for delivery in 2016.

Finally, it is hoped that the delegates of the workshop benefited from the experience and the networking opportunity that the event provided. The UK team in particular gained a great insight into the water research and technology agenda in India and were very much impressed by the depth and quality of research that has been delivered by Indian colleagues. There are clear opportunities to work in partnership to deliver projects which don't just benefit the UK or India but provide solutions that can be applied internationally to address the global strategic objectives set out in the Sustainable Development Goals. The UK team are very much looking forward to continuing the extremely valuable collaboration with Indian collaborators.