

2025 Ineson Lecture



Wednesday 19th November at the Geological Society, Burlington House, London.

Sustainable Groundwater: Old and New

The International Association of Hydrogeologists [British National Chapter](#), together with the [Hydrogeological Group](#), are pleased to announce the 2025 Ineson Lecture on the theme of Sustainable Groundwater: Old and New. The Ineson Lecture this year will also host the 2025 Darcy Lecture [NGWA Darcy Lecture 2025](#).

Programme

09:30 am Registration & coffee in the Lower Library

10:30 am Welcome, Harriet Carlyle (Chair of IAH GB Chapter)

10:40 am Keynote Speaker Introduction

10:45 am [Keynote speaker: 2025 Darcy Lecture – Dr. Grant Ferguson \(University of Saskatchewan\) Living Fossils: Ancient Groundwater in the Anthropocene](#)

11:45 am Rob Soley (WSP) - Groundwater is great! Large cuts to abstraction are unwise

12:10 pm Alastair Black (Groundwater Science) - What is the definition of 'Sustainable' in our management decisions?

12:35 pm John Day Bursary

12:40 pm Lunch & Hydro Group AGM 1 hr

13:40 pm Bentje Brauns (British Geological Survey) - What can standardised indices reveal about hydrogeological connectivity and drought dynamics across scales?

14:05 pm Mark Grout (Environment Agency) - The use of groundwater to buffer droughts and the quest for sustainable abstraction across the East Anglian region of the UK

14:30 pm Hydrogeological Group Medal Awards

14:40 pm Tea

15:10 pm Ineson Lecture Introduction

15:15 pm [Ineson Lecture: Dr. Bridget Scanlon \(The University of Texas at Austin\) Conjunctive Management of Surface Water and Groundwater to Increase the Sustainability of Global Water Resources](#)

16:15 pm Panel discussion

17:00 pm Drinks reception in the library

Speaker Abstracts

[Dr. Grant Ferguson \(University of Saskatchewan\)](#) *Living Fossils: Ancient Groundwater in the Anthropocene.* The bulk of groundwater on Earth is fossil, having been recharged more than 12,000 years ago. Past definitions classified these waters as non-renewable because the aquifer systems containing them are not replenished on human timescales. Scrutiny of this definition suggests that it is overly simplistic and may result in preventing access to groundwater to improve water security in some cases or while failing to prevent excessive depletion in others. In many aquifers, groundwater residence times are long because of their large storage volumes; there is no reason to believe that using groundwater from large aquifers is less sustainable than using groundwater from smaller aquifers if recharge rates have not varied appreciably over time. In cases where past climates were much wetter, there has been concern that groundwater will not be replenished under current conditions. Examination of groundwater age distributions suggests that this situation is relatively uncommon. Substantial groundwater storage anomalies are unlikely to persist in areas containing fossil groundwater due to the differences between the rates of transport and hydraulic diffusion, except in very large regional aquifers. This difference in behaviour between storage and transport has been confirmed by recent studies using stable isotopes of noble gases to reconstruct past water table depths. Changes in storage associated with past climates appear to be smaller than those associated with anthropogenic depletion of groundwater, including cases where modern and fossil groundwaters have been extracted. The long response times of many groundwater systems allow them to mediate water and solute fluxes within the Earth system over long time periods. Their lack of sensitivity to current climate changes will make them a strategic resource, if used at appropriate rates.

[Rob Soley \(WSP\)](#) *Groundwater is great! Large cuts to abstraction are unwise.* Our need to access and manage groundwater storage is becoming more acute to sustain public supplies, agriculture, industry, wetlands and river flows through droughts as the climate shifts. Water bills are already stretching affordability levels for many to fund reductions in sewage pollution, the government wants to get growth going and build more houses, and the effectiveness of measures to reduce water consumption and mains leakage is uncertain. At this critical time, our regulators have set an Environmental Destination challenge of reducing groundwater abstraction in England by ~2,600MI/d – over one third of current pumping - with the aim of complying with naturally-referenced river flow targets. Most of these cuts would fall in headwater catchments where seasonal storage and flow mechanisms are most active in reducing low flow impacts below summer groundwater abstraction rates. Given the uncertainty of realising demand reductions, replacing these drought-resilient sources will put additional stress on strategic new surface reservoirs, desalination plants and effluent recycling schemes which are mostly needed to build more supply security for the future. The hydro-ecological evidence underpinning the default river flow targets is also poor, so we risk wasting a lot of money for limited biodiversity gains.

This presentation will focus on the technical reasons why groundwater is such a great resource in many different settings, using the Wessex Basin chalk as an example, and argues that we would be unwise to lose our access to manage it more smartly for the future for both supplies and environmental support.

[Alastair Black \(Groundwater Science\)](#) *What is the definition of 'Sustainable' in our management decisions?* Much of the UK water management decisions are based on low flow metrics; commonly involving flow naturalisation, nationally scalable estimates of ecological sensitivity to flow reductions and percentile methods. We also use EU-WFD derived classifications, GIS based catchment water balances and in some instances, restrictive, wetland specific metrics.

But do these constitute a defensible definition of sustainability? Can the present methods be augmented to reflect uncertainty in cases where there are not bespoke hydroecological or related surveys to link sustainability to pressure? How can present precise but inaccurate models be used to defensibly imply no-harm on receptors.

This study meets a need where sustainability decisions are required, but the definition of what is the ecological need is uncertain.

In this talk we also raise that models and other forms of decision-making tools should be without bias, but the optioneering can be undertaken in a Precautionary manner. This is counter to tools being built to be Precautionary and further applied in a Precautionary manner.

This talk is intended as a proactive discussion on why and how we can move away from this emerging direction of cessation of groundwater use.

[Bentje Brauns \(British Geological Survey\) - What can standardised indices reveal about hydrogeological connectivity and drought dynamics across scales?](#) Groundwater systems respond to droughts in diverse and often delayed ways, shaped by multiple factors such as aquifer properties, recharge processes, and land use. This talk explores how standardised indices, such as the Standardised Groundwater Index (SGI), can support the interpretation of groundwater drought dynamics across scales—particularly when working with large, heterogeneous datasets. While such indices offer a useful lens for identifying broad patterns, they also simplify site-specific behaviour. Cluster analysis of groundwater hydrographs reveals spatially coherent response types, reflecting differences in system memory and connectivity. These findings highlight both the potential and the limitations of using standardised approaches to understand groundwater droughts. Within this talk an example of an SGI analysis of a large a large (~3000 sites) set of groundwater time series from 1986 to 2015 is presented and shows large-scale patterns in groundwater droughts.

[Mark Grout \(Environment Agency\) - The use of groundwater to buffer droughts and the quest for sustainable abstraction across the East Anglian region of the UK.](#) This talk will describe the water resources supply system that has been developed across East Anglia to show the extent to which groundwater augmentation has been developed in order to buffer the spatial variations in demand, and to mitigate for low streamflows in dry weather. The last 25 years has seen a changing emphasis from the development of groundwater for water supply to an ambition to restore a more natural hydrological regime. The implications and challenges of this change for water supply and groundwater augmentation are highlighted.

The East Anglian region, in common with other regions of the UK, shows spatial variations in demand; there are significant centres of demand around Cambridge and South Essex. East Anglia is also one of the driest areas of the UK and is susceptible to periods of prolonged dry weather. Fortunately, the region is underlain by the Chalk aquifer and its adjoining aquifers. Over time, the Chalk aquifer system has been developed for public water supply, but also to augment river flows to buffer the effects of the spatial variation in demand and seasonal changes in water availability. This talk will describe the water resources supply system that has been developed across East Anglia to show the extent to which groundwater augmentation has been developed.

Over the last 25 years, a framework of groundwater models has been developed for East Anglia to support water resources and water quality management. The models are allowing the Environment Agency to investigate the effectiveness and potential future operation of groundwater augmentation schemes. Many of the augmentation schemes were developed without the benefit of groundwater models or at best, much simpler groundwater models. The current framework of groundwater models is providing the opportunity to review these important groundwater augmentation assets.

The last 25 years has also seen a concerted downward pressure on groundwater abstraction. This downward pressure has been exerted through the Restoring Sustainable Abstraction Programme initiated in 1997, the Habitats Directive and the Water Framework Directive. Many of the watercourses across East Anglia are also now identified as Chalk Streams under the initiative to restore Chalk Stream flows. Not least, the Environment Agency has recently launched its National Framework, including the Environmental Destination, a programme that is working towards an ambition of significantly lower groundwater abstraction across the Chalk of South East England, particularly in view of potential climate change scenarios. The implications and challenges of this ambition for water abstractors and groundwater augmentation are highlighted.

[Dr. Bridget Scanlon \(The University of Texas at Austin\) Conjunctive Management of Surface Water and Groundwater to Increase the Sustainability of Global Water Resources.](#) Managing global water resources is becoming increasingly challenging with increasing irrigation water demand and intensifying climate extremes. Our analysis of global water storage trends benefits from advances in remote sensing, especially GRACE satellite data, global and regional modelling, and expanding monitoring networks.

GRACE satellite data show declining, stable, and rising trends in total water storage over the past two decades in various regions globally. The causes of water storage variability are primarily linked to human drivers, particularly irrigation, and climate extremes, especially droughts and floods. GRACE satellites show large-scale water storage

depletion over the past two decades in NW India, Middle East, N Africa, and SW US. Groundwater monitoring and regional modelling provide longer-term context over the past century, showing rising water storage in NW India, central Pakistan and the NW US, and declining water storage in parts of the US High Plains and US Central Valley. Areas of stable or rising water storage show potential for irrigation expansion, including many parts of Africa and humid E US. Water resource resilience can be increased by conjunctively managing surface water and groundwater and storing water in surface and subsurface reservoirs from wet climate cycles for use during droughts. Examples of conjunctive surface water and groundwater management include combining canal irrigation and groundwater irrigation in NW India and SW US. Inefficient surface water irrigation during wet periods can be used to recharge depleted aquifers for use during droughts, as in the SW US and using managed aquifer recharge.

A diverse portfolio of water management solutions, in tandem with managing groundwater and surface water as a single resource, can help address human and ecosystem needs while building a resilient water system. The visual power of GRACE satellite data has helped communicate water storage variability to the public and influence water policy in many regions, including India and the US.

Speaker Biographies



Dr Grant Ferguson is a professor of hydrogeology in the Department of Civil, Geological and Environmental Engineering at the University of Saskatchewan. He also holds a joint appointment in the School of Environment and Sustainability at the University of Saskatchewan and is an adjunct professor at the University of Arizona and University of Waterloo. Ferguson holds a B.Sc. from the University of Waterloo and a Ph.D. from the University of Manitoba. His research focuses on the hydrogeology of deep groundwater systems, paleohydrogeology, the hydrogeology of the Canadian Prairies and sustainable development of groundwater resources. Ferguson is currently vice president, North America for the International Association of Hydrogeologists and has served as President of their Canadian National Chapter. He is also an associate editor for the journal Groundwater.



Rob Soley is a hydrogeologist who has focused on water resources work overseas and in the UK for the last 36 years. He helped the Environment Agency design many of its spreadsheet, GIS and coding tools to assess the acceptability of abstraction and discharge impacts on rivers, wetland and estuarine/coastal receptors. Most of the examples in the talk are drawn from the regional groundwater, river flow and wetland models which Rob has led the development and use of across the Sandstone, Chalk, Limestone and gravel aquifers of England. He is half way through releasing a series of 'Groundwater is Great!' videos on LinkedIn exploring the hydrogeological processes and regulatory issues summarised in this presentation



Alastair Black is a hydrogeologist and software developer with over twenty years of experience in water-resources modelling, mining hydrogeology, and sustainable groundwater management. As Director of Groundwater Science Ltd, he has been part of the team in more than sixty groundwater and surface-water modelling projects for regulators, water companies, and industry. His interests focus on improving conceptual accuracy and predictive reliability in water-resource assessments through innovative use of numerical modelling and software development. Alastair aims to continue to promote sustainable abstraction and evidence-based decision-making across the sector.



Dr. Bentje Brauns is a Senior Hydrogeologist at the British Geological Survey (BGS). Her academic journey began with a PhD focused on groundwater–surface water interactions and nutrient exchange in Asia. Since then, she has built a diverse portfolio of work addressing groundwater contamination, recharge dynamics—including drought-related challenges—and field-based hydrogeological investigations across Europe, Africa, and Asia. At BGS, Bentje has been contributing to international research since 2018, leading and supporting projects that tackle complex groundwater issues with an emphasis on collaborative solutions and interdisciplinary work.



Mark Grout. My career in groundwater started just over 40 years ago when I was awarded a Ph.D. on the numerical modelling of radial flow to a pumping well. The Ph.D. led on to a research fellowship, working on a contract to review the reliable outputs of the groundwater sources of the then Lee Valley Water Company, now part of Affinity Water. Lee Valley Water Company supplied water to most of Hertfordshire and the eastern part of Essex. At the end of the research fellowship, I joined Anglian Water Authority as a groundwater modeller. Following the privatisation of the water industry, I transferred to the National Rivers Authority and then the Environment Agency, still based within the former Anglian Region, covering Lincolnshire and East Anglia. Throughout the 1990s, the focus of groundwater modelling within the Environment Agency was delineating groundwater protection zones for the purposes of the new national Groundwater Protection Policy. At the end of the 1990s, I wrote a Strategy aimed at the development of a framework of groundwater models covering

all the main aquifers of the Anglian Region that could form the basis for decision-support with regard to groundwater resources and groundwater quality management. Since the year 2000, I have led a programme to deliver this framework. I also led the application of the groundwater models in support of the Restoring Sustainable Abstraction Programme, the Habitats Directive Review of Consents, the Water Framework Directive and then to a complete review of the original groundwater protection zones. My current work continues to focus on the maintenance and refinement of the Anglian groundwater models, and their operation in support of a range of water resources business drivers



Dr. Bridget Scanlon is a Research Professor at the Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin. Her current research focuses on various aspects of water resources, including global assessments using satellites and modelling, management related to climate extremes, and water energy interdependence. She has authored ~ or co-authored ~200 publications. Dr. Scanlon is an AAAS, AGU and GSA Fellow and a member of the National Academy of Engineering.

Posters

John Day Bursary Award – Winner

A review and update of an existing model for sustainable water supply in Cox's Bazar Mega Camp.

Hasan Kadodia

University of Birmingham

This project addresses groundwater resources for a mega refugee camp, Cox's Bazar, in south-east Bangladesh for Rohingya people who have fled Myanmar. Since 2017, the rapid expansion of the Mega Camp, which accommodates over 1 million refugees, had caused the substantial increase in demand for drinking and sanitation water, resulting in intensified groundwater abstractions. Additionally, accommodating the camp's expansion has meant further destruction of existing natural forests, causing a change in local hydrological conditions, affecting the average annual rainfall and the groundwater recharge. Consequently, groundwater levels in wells across the Mega Camp has been steadily declining as abstraction continues to meet growing demand. To clarify current conditions, an expanded database was collated: observation well hydrographs, rainfall and PET records, updated production-well, population datasets, and published pumping test summaries from earlier work. Datasets were processed, but a time series was not reconstructed given project time constraints. The inputs were used to refresh the existing numerical model and to suggest a more efficient groundwater management rather than detailed forecasts. The study suggests practical measures to ease aquifer stress, selective use of deeper formations such as the Tipam Sandstone, capture and storage of monsoon runoff on elevated ground, encouragement of deeper drilling north of the Mega Camp where transmissivity values are usually higher. The work provides a coherent data foundation and clear actions for integrated groundwater management and adaptive planning. Key limitations are the absence of transient target series in calibration, and the lack of a newly reconstructed time series. Conclusions therefore emphasise observed records and operational recommendations rather than precise predictions.

John Day Bursary Award – Runner-up

Ground Source Heat Potential for the University of Birmingham

Mateusz Pandzierski

University of Birmingham

This project further develops an existing FEFLOW heat transport model of the sandstone aquifer beneath the university campus, in the context of assessment of potential for open loop ground source heating and cooling. A refined conceptual model of groundwater and heat movement is developed, including interaction between the aquifer and surface water boundaries, and anisotropy of the sandstone. The role of these factors in the viability and long-term performance of the proposed geothermal scheme is analysed using the updated model.

Ecosystem Hydrological Monitoring – Implications for Groundwater Management

Regan, S.^{1,2}, Cushnan, H.³, O'Connor, M.³, and Mackin, F.³

¹ Scientific Advice and Research Directorate. National Parks and Wildlife Service. Dublin; ² School of Earth Science. University College Dublin. Dublin; ³ RPS Consulting Engineers. Belfast.

The National Parks and Wildlife Service is the State Agency responsible for nature conservation of national and international protected areas in Ireland. Associated with this, is a scientific monitoring programme that has been developed for ecosystems of particular significance (peatlands, coastal wetlands, grasslands and rivers). A primary purpose of the monitoring network is to collect long-term scientific observations on ecological, hydrological and carbon dynamics in order to better understand ecosystem dynamics and its response to environmental pressures (e.g. land-use, pollution and climate change). Groundwater monitoring is an integral part of the monitoring scheme, informing conservation management, but also as information for regional hydrology, with many observation sites being located in important municipal water supply and recharge areas.

This poster will present the monitoring network, preliminary results and insights into thresholds for sustainable groundwater abstraction in areas with important ecological receptors.

Assessing the resilience of public water supply boreholes to future drought

Kirsty Upton, Matthew Arran, Chris Jackson, Ben Marchant, Setareh Nagheli

British Geological Survey

Water companies must be able to assess the amount of water they are able to supply -Deployable Output (DO) - and how this might change under future drought conditions, which are predicted to be more frequent and severe. Water companies currently lack adequate tools for assessing future changes in groundwater DO, instead relying on historical data to make a 'best guess'. We present the development of a modelling framework – combining detailed source scale groundwater models, simulation of regional groundwater level hydrographs using Aquimod, and machine learning-based model emulation – that can be used to produce seasonal to multi-decadal forecasts of groundwater source performance.

Linking SAR Backscatter Intensity to Ecohydrological Dynamics of Temperate Bogs

Mahdi Khoshlahjeh Azar^{1,2}, Alexis Hrysiewicz^{1,2}, Shane Donohue^{2,3}, Shane Regan⁴, Raymond Flynn⁵, Florence Renou-Wilson⁶, Eoghan P. Holohan^{1,2}

¹UCD School of Earth Sciences, University College Dublin, Dublin, Ireland

²Research Ireland Centre for Applied Geosciences (iCRAG), University College Dublin, Dublin, Ireland

³UCD School of Civil Engineering, University College Dublin, Dublin, Ireland

⁴National Parks and Wildlife Service, Ireland

⁵School of Natural and Built Environment, Queen's University of Belfast, Belfast, United Kingdom

⁶School of Biology and Environmental Science, University College Dublin, Dublin, Ireland

Peatlands play a crucial role in regulating water flow, maintaining groundwater recharge, and preserving water quality. However, climate variability and human disturbance increasingly threaten their function, potentially leading to carbon emissions, biodiversity loss, and poor water quality. Understanding groundwater dynamics within peatland systems is therefore essential for sustainable water resource management. The widespread distribution of damaged peatlands makes these processes challenging. Synthetic Aperture Radar (SAR) satellites provide consistent, large-scale observations at high resolution, even under cloudy conditions. Yet, the links between SAR backscatter and peatland ecohydrology remain only partly understood. Our study examined how cross-polarized C-band SAR backscatter, VV (vertical transmit/vertical receive) and VH (vertical transmit/horizontal receive), relates to temperate bogs. Time series of SAR backscatter intensity showed annual oscillations: maxima in winter-spring and minima in summer-autumn, mainly reflecting soil moisture changes controlled by groundwater and meteorological condition. We found that industrial cutaway peatlands exhibit stronger seasonal VV intensity swings than near-intact bogs, reflecting more extreme drying-wetting cycles that can influence local groundwater dynamics. VH intensity was highest in shrub-dominated areas and lowest in cutaway and moss-dominated bogs, indicating vegetation-driven differences in water retention and infiltration. Importantly, shifts in SAR backscatter reveal the hydrological effects of human disturbance and early restoration, highlighting SAR's potential as a tool for monitoring peatland management practices that support sustainable groundwater resources.

Restoring Sustainable Abstraction in Nottinghamshire

Phil Hubbard¹, Matilda Beatty², Ben Harvey-Galliers¹, Andrew Davey³, Alberto Scotti³

¹Stantec; ²Severn Trent; ³APEM

The East Midlands Permo-Triassic sandstone aquifer is a vital source of water for large parts of Nottinghamshire and South Yorkshire, with abstraction by Severn Trent, Anglian Water and Yorkshire Water. Since 2010, Stantec and APEM have been investigating abstraction-induced low flows for Severn Trent in tributaries of the River Idle and the River Trent. As a result of these investigations, Severn Trent committed in 2020 to reduce abstraction across the wellfield by 23.5 MU/d by 2030, alongside river restoration measures in four waterbodies.

Such an abstraction reduction posed a significant challenge for the local water supply, and has required investment in alternative supplies and substantial reconfiguration of the network. Stantec has supported Severn Trent in the development of a sustainable abstraction strategy for the area, using the EA's East Midlands Yorkshire groundwater model to target reductions at the most environmentally beneficial sources, while also respecting operational constraints and avoiding potential disbenefits. The project highlights the importance of conjunctive use for effective management of water resources, as well as the need to integrate licence changes with catchment measures to improve environmental outcomes.

Lough Fea Sand and Gravel Aquifer - Dual approach to estimating recharge to a shallow superficial aquifer

Paul Wilson and Rebecca Ní Chonchubhair

Geological Survey of Northern Ireland

The Lough Fea Sand and Gravel Aquifer is a productive superficial aquifer which is currently of interest to Northern Ireland Water due to its potentially high yields (>1 ML from shallow boreholes) and potential financial savings as its high elevation allows water to be gravity fed to users. Due to its strong connection to surface water flows, a robust understanding of the groundwater resource is required to ensure it is managed sustainably. This study estimates groundwater recharge through the FAO method which utilises Met Office weather data and superficial mapping and through the Water Table Fluctuation Method which utilises actual groundwater level data from a borehole located adjacent to the weather station. The proximity of the observation well to the weather station allows for a comparison to be made between both methods.

Dynamics of Groundwater Recharge and Land Subsidence in the Kathmandu Valley

Anoj Khanal¹, Hayley Saul¹, Prakash Pokhrel^{2,3}

¹Heritage for Global Challenges Research Centre, Department of Archaeology, University of York, York YO1 7EP, UK; ²School of GeoSciences, University of Edinburgh, Edinburgh EH8 9XP, UK; ³Department of Mines and Geology, Government of Nepal, Lainchaur, Kathmandu 44600, Nepal

In recent years, Kathmandu Valley has witnessed massive land subsidence with rate of subsidence exceeding 20 cm/yr in certain locations and groundwater withdrawal is believed to be a major driver behind this subsidence. This research examines the relationship between groundwater age, recharge process, groundwater subsidence and existing land use practices, exploring the drivers of ongoing subsidence. Recent data shows Kathmandu Valley has a mixed groundwater recharge environment where modern water is mixing well with pre-modern water, suggesting a complex heterogeneous recharge environment. The existing multi-aquifer pumping system, combined with a mixed recharge environment, creates favourable conditions for land subsidence. Current subsidence data reveal a strong correlation between zones characterized by intensive groundwater extraction and the presence of older groundwater, both of which exhibit higher subsidence rates. This suggests that the recharge environment of the valley plays a critical role in driving the subsidence. With increasing water demand and the lack of sustainable water alternatives, the magnitude and spatial extent of subsidence are likely to intensify in the coming years, posing a substantial challenge for nearly four million inhabitants of Nepal's capital city.

Revisiting groundwater for future resilience.

Stuart Allen, Natalie Kieboom, Sian Loveless, Amy Wilcox

Environment Agency

The Environment Agency (EA) plays a key role in managing water resources in England. With a changing climate and new demands on water sources (for example, economic growth, net zero and AI) we need a better understanding of the potential role groundwater can play in managing these challenges.

This poster will share findings from previous EA work in this area (including droughts, brackish water sources) and where we see evidence gaps and opportunities for future research into groundwater resources (for example, improving models of surface water-groundwater interactions and water management units).

Sand dams as year-round groundwater supply in water scarce regions.

Alison Parker

Cranfield University

Sand dams are a way of increasing groundwater availability in water scarce regions with long dry seasons. To measure how far into the dry season they provide water 30 handpumps next to sand dams were fitted with data transmitters which measured when the pump was being used. At 21 wells, abstraction was still being recorded at the end of at least one long dry season; however, high spatial and temporal heterogeneity between pumps and seasons means that not all sand dams deliver reliable water supply year-round.

Building strategic groundwater monitoring capacity into natural capital assessments

Elena Armenise, Mario Manganaro, Sharon Thomas

Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH, UK

The Natural Capital and Ecosystem Assessment (NCEA) programme is Defra's largest research and development programme, designed to build strategic capacity for monitoring and assessing natural capital and ecosystems across England. It will improve the quantity, quality, and relevance of environmental data and system-level insights, which will ultimately help government, businesses, and the public make more informed decisions and environmental policies.

As part of this initiative, the Environment Agency is establishing five new monitoring networks focused on groundwater ecology, groundwater quality, groundwater level, groundwater temperature, and groundwater dependent wetlands. These networks will deliver unbiased and statistically robust assessment of the groundwater condition across the country, filling critical evidence gaps, providing a more holistic view of environmental health and resilience, and informing long-term policy and investment decisions for sustainable groundwater management.

Sustainable groundwater in Scotland: the environmental tracer baseline

George Darling¹, Laura Holliday¹, Alan MacDonald¹, Leo Peskett², Daren Goody^{1,3}, Brigid Ó Dochartaigh¹

¹British Geological Survey; ²Heriot Watt University; ³currently UKCEH

The growing contribution of groundwater to Scotland's water supply makes it important to establish 'baseline' aquifer conditions against which to evaluate future changes due to abstraction, pollution and climate change, all factors that determine resource sustainability. The SEPA/BGS Baseline report series (<https://nora.nerc.ac.uk/id/eprint/519084>) laid a firm foundation, but prioritised water quality over factors like provenance and age. This poster outlines progress regarding the latter across Scotland, in the form of improved maps of stable isotopes in groundwater, and age-tracer information from a range of aquifers. These will allow better evaluation of any future changes in individual aquifers as they are developed.

Groundwater Relief Poster

Oliver Wale

Groundwater Relief

Since 2021, Groundwater Relief and Acted have been supporting the Northeast Syrian water authorities with a hydrogeological study of the Upper Khabour River Basin in Al-Hasakah Governorate. This work is in response to prolonged water insecurity and the drying of Ras-al-Ein spring and the Khabour River.

Key activities to date include a desk-based hydrogeological study, establishment of groundwater and rainfall monitoring systems, and pumping test investigations of major wellfields near Hasakah and Qamishli cities.

Initial findings indicate that water scarcity in Al-Hasakah is driven by a complex mix of climatic, anthropogenic, political, and geological factors. In particular, the reliance on non-renewable deep aquifers and the prevalence of anhydrite in the upper aquifers contribute to a high prevalence of elevated groundwater salinity. However, limited zones of relatively fresh groundwater are found beneath local volcanic basalt formations, which are increasingly exploited to supply drinking water to Hasakah city via water trucking.

Next steps in the programme include downhole geophysical surveys, continued data collection, refinement of the existing Leapfrog 3D geological model, and development of a numerical groundwater flow model to support informed, scenario-based decision-making by local authorities.

Assessing and Mitigating Impacts of Quarry Dewatering: A Hydrogeological Approach with a Case Study from Scotland

Chris Woodhouse and Hannah Muir

Envireau Water


Dewatering from quarries can impact abstractors, river flow and the environment and a robust hydrogeological conceptual model is essential to enable impacts to be predicted and appropriately mitigated. A case study from a hard rock quarry in Scotland shows how, through targeted data collection and conceptualisation, impacts can be assessed and mitigation designed to protect neighbouring private water supplies and an ecological SSSI.

A Wee Dram of Resilience: Water Supply Boreholes Supporting the Distilling Industry in Scotland.

Chris Allman

Envireau Water

To increase climate resilience and support business growth, two new production boreholes were installed to supplement old spring sources at an existing distillery on Speyside. A series of ground investigations were initially completed to support the development of the new groundwater sources, ensuring that the final scheme was developed prioritising source efficiency and sustainability, and ensuring protection to the nearby designated sites. Two boreholes were successfully drilled and tested, securing a more robust and drought-resistant water supply and enabling increased operational capacity and long-term sustainability.



Slides are available upon request.
Please contact: benaun@bgs.ac.uk

INESON MEETING, BURLINGTON HOUSE, LONDON, 19 NOV 2025

What can standardised indices reveal about hydrogeological connectivity and drought dynamics across scales?



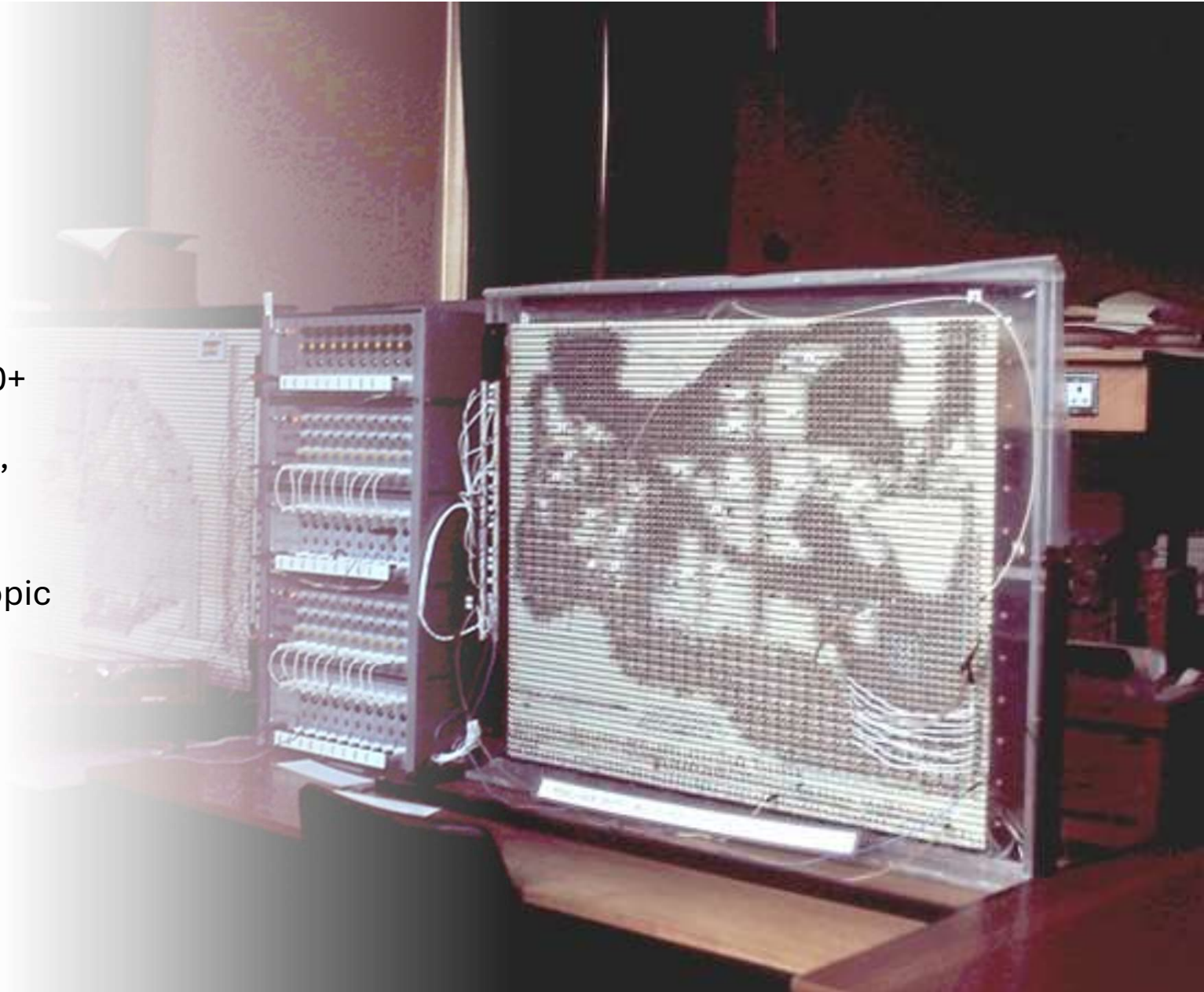
BENTJE BRAUNS AND MANY MORE

The Use of Groundwater to Buffer Droughts and the Quest for Sustainable Abstraction Across East Anglia, UK

Dr Mark Grout
Environment Agency
Ineson Event 2025

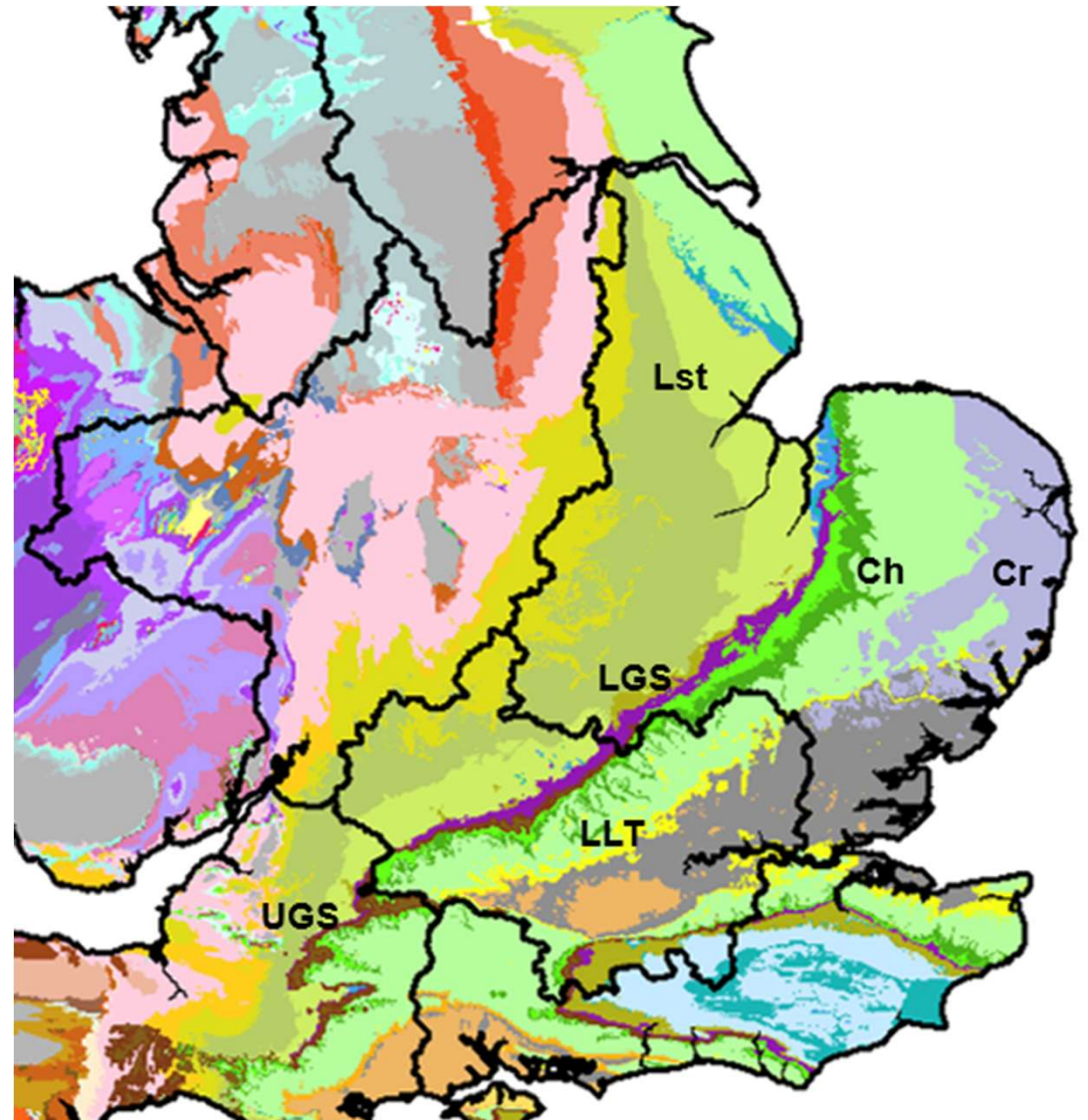
Introduction

- Career in groundwater 40+ years
- Focus on 'Anglian Region'
- 'Water Scarce'
- Good focus for today's topic
- What is the 'available groundwater resource'?



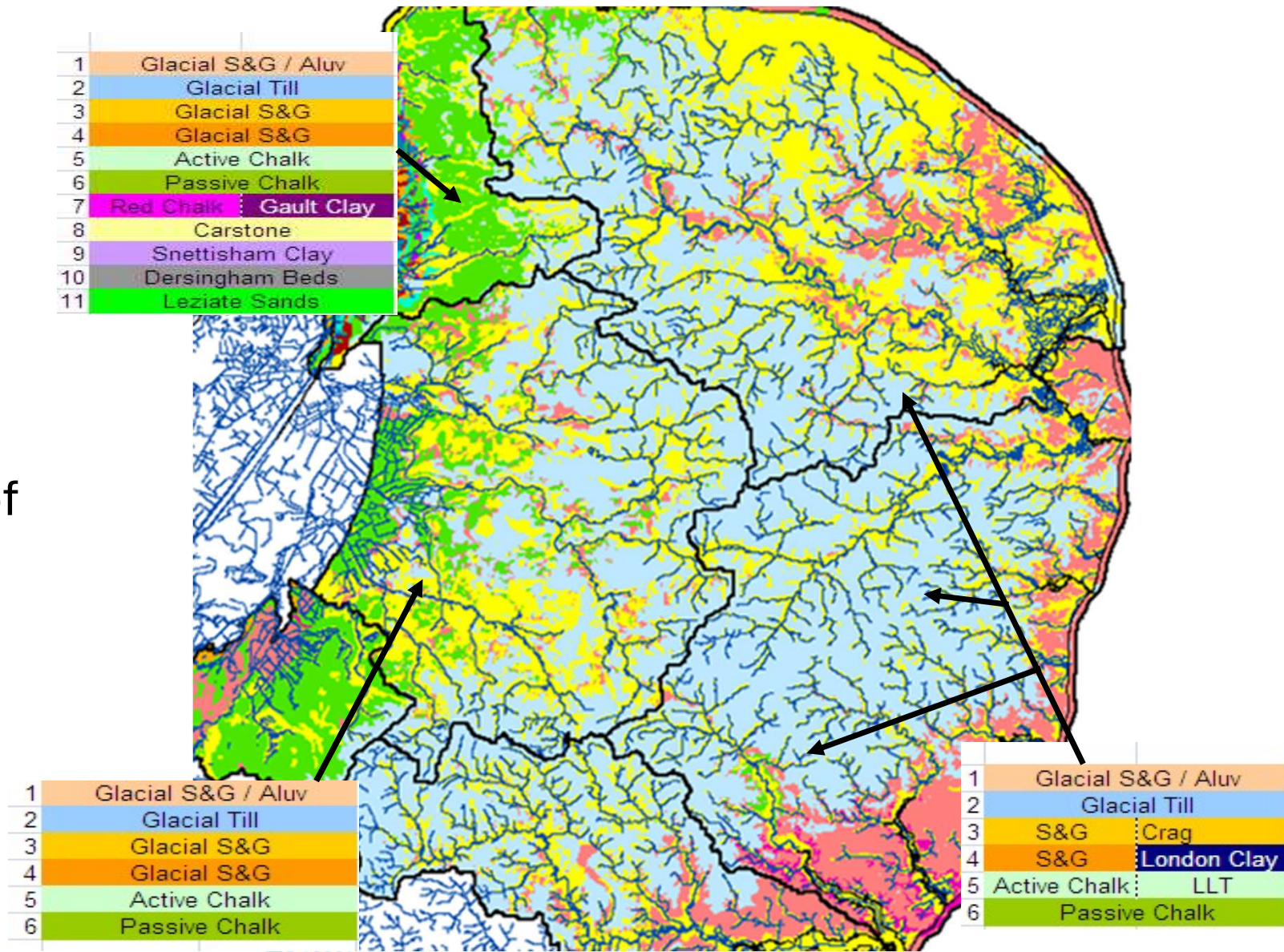
East Anglia

- Underlain by the Chalk aquifer system
- Extensive glacial deposits
- Driest part of UK
- Lot of abstraction
- Predominant land use - agriculture
- Need for irrigation



East Anglia Solid and Drift Geology

Large quantity of
groundwater
storage with the
overall aquifer
system



Effective Rainfall

Irrigation Demand –

- Greatest in East Anglia
- Relatively evenly spread across East Anglia

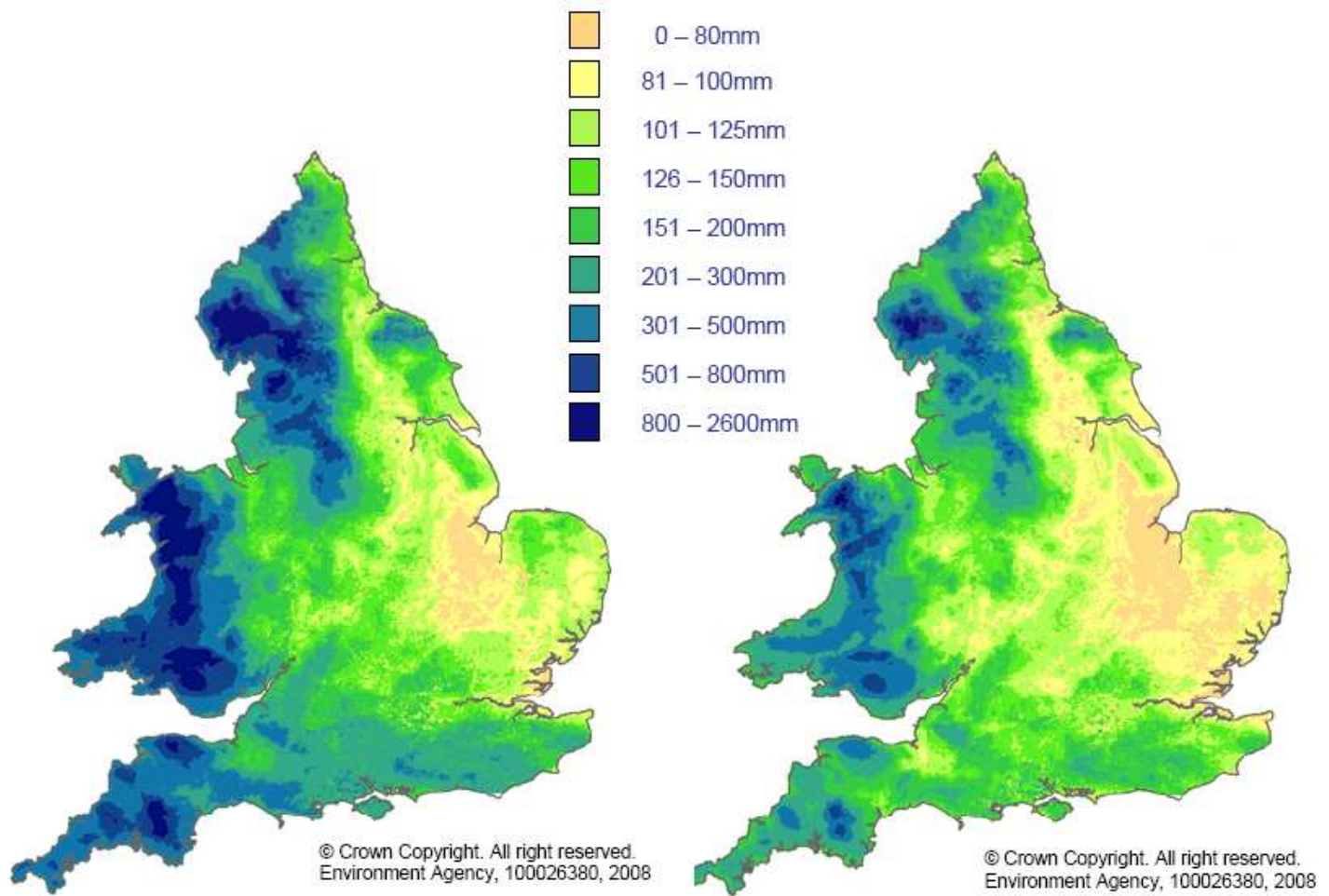


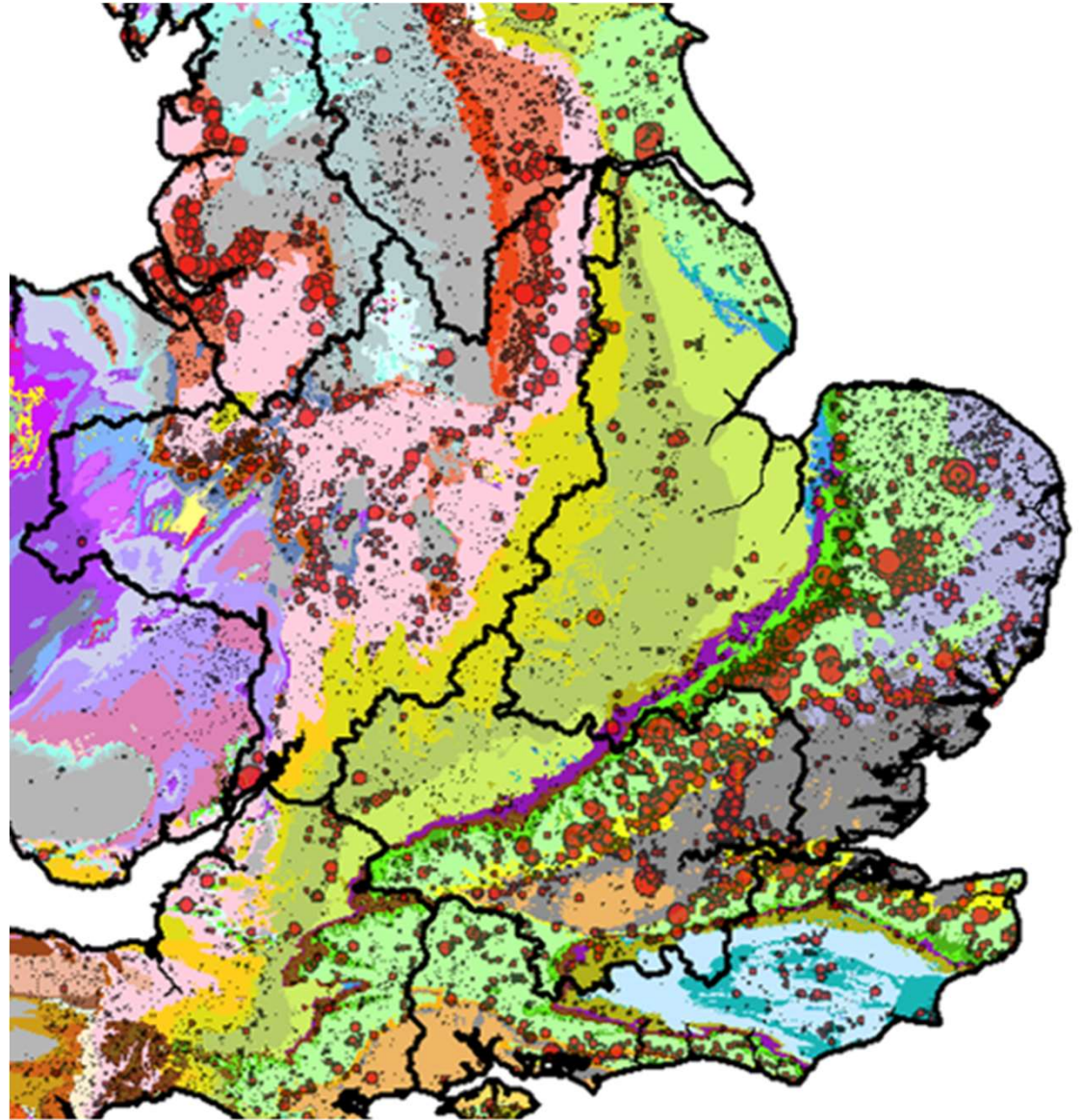
Figure 2a
Winter effective rainfall
(October to March)

Figure 2b
Summer effective rainfall
(April to September)

Groundwater Abstraction

Groundwater Abstraction -

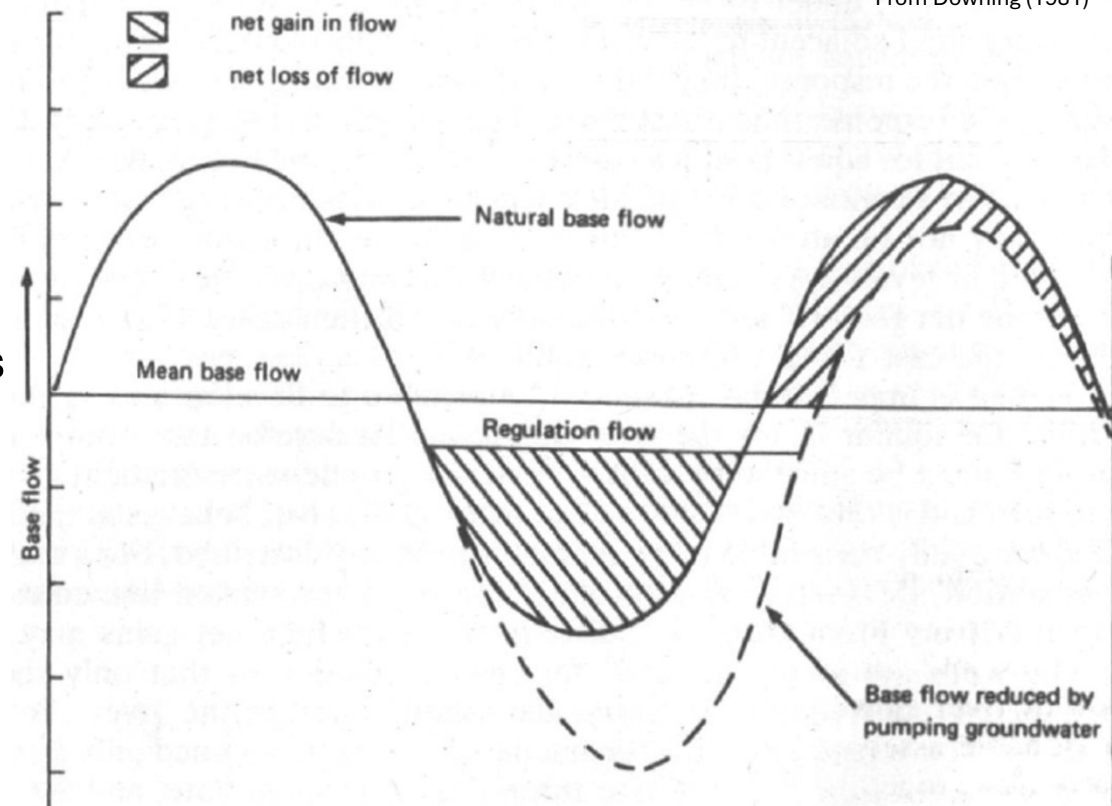
- Public Water Supply
- Agriculture
- Industry
- Other e.g. golf courses
- Groundwater Augmentation



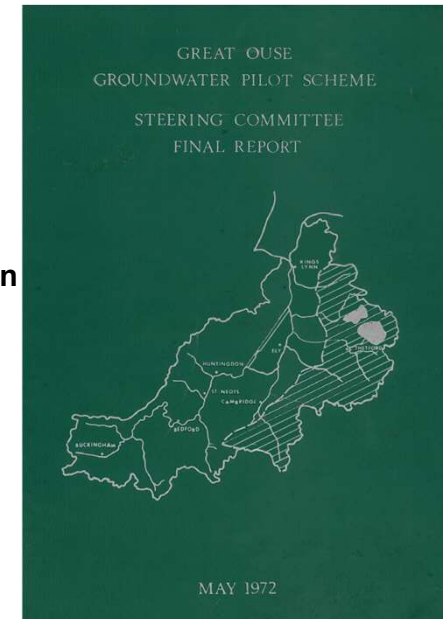
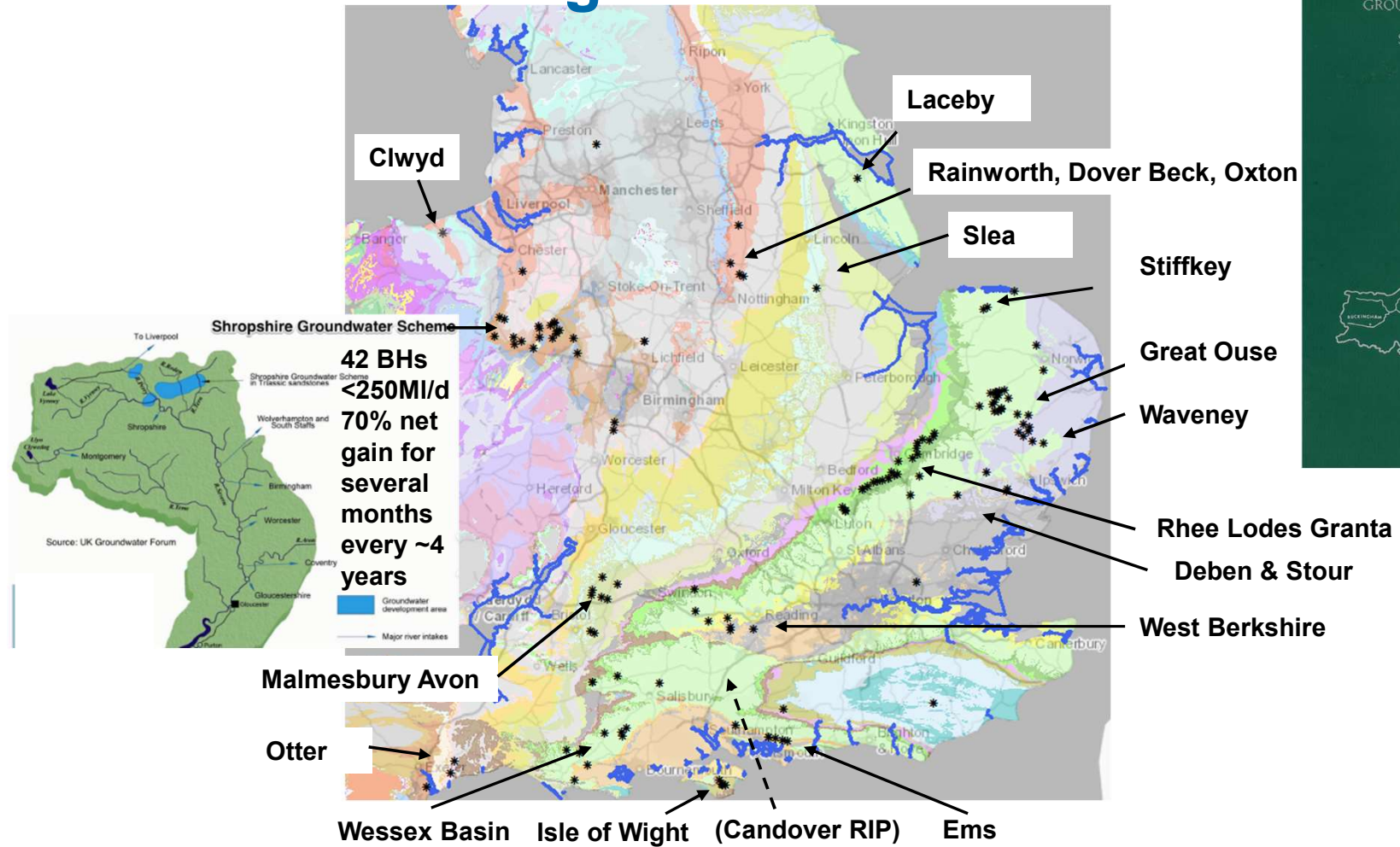
Groundwater Augmentation Schemes

- Conjunctive Use – GOGS, SAGS, WAGS – surface water vs groundwater drought
- 2025 experience
- Environmental/River Support – Rhee, Lodes-Granta, Deben
- Water company River Support Schemes
- Original idea – Water Resources Board – Jack Ineson?
- Philosophy for sustainable groundwater resource development – 1960s onwards
- Augmentation to buffer droughts
- Issue of Net Gain

From Downing (1981)



Groundwater augmentation schemes



19 Nov 2025 – Geological Society, Burlington House, London

IAH Events

Ineson Lecture 2025

Sustainable Groundwater: Old and New. Save the date!

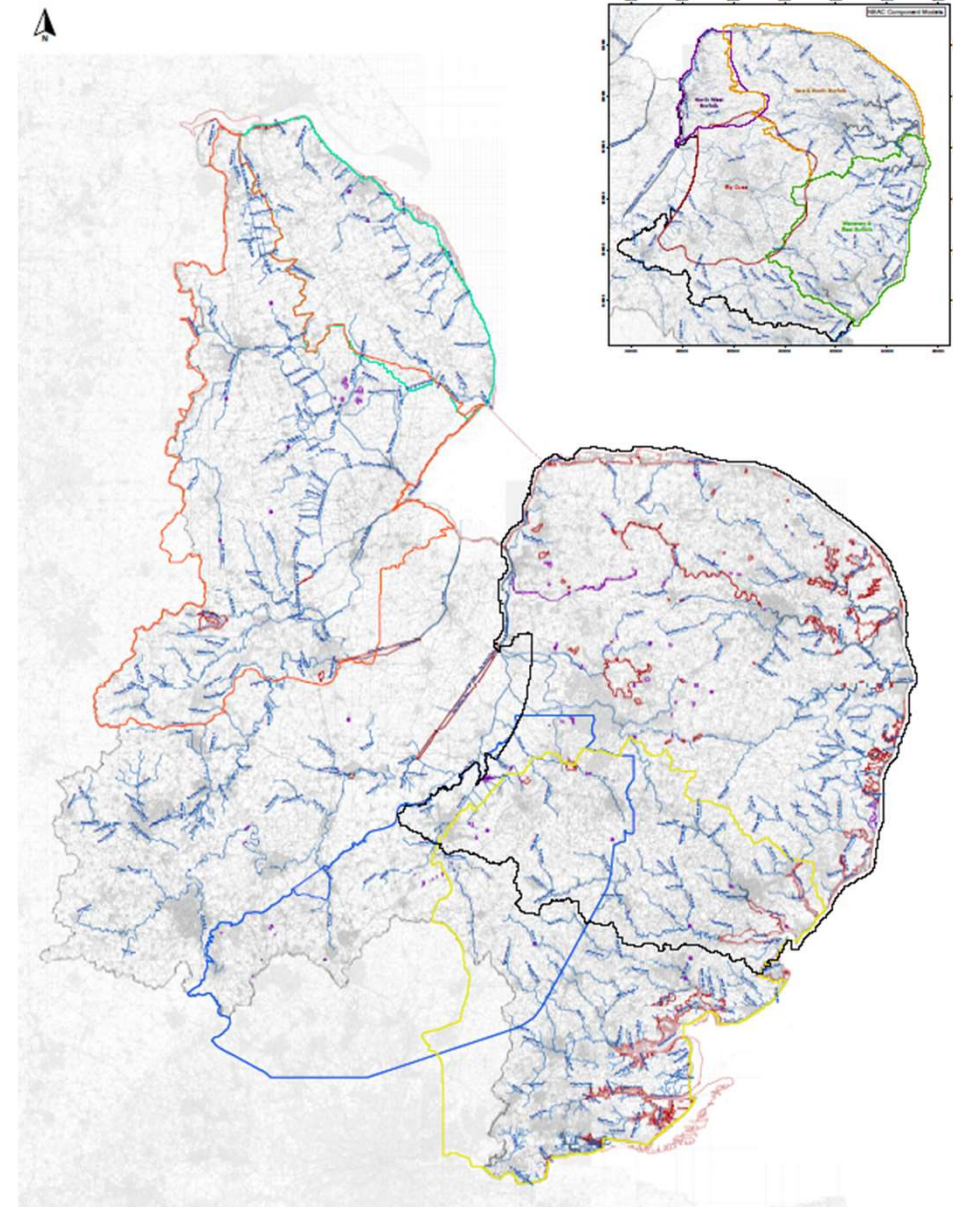
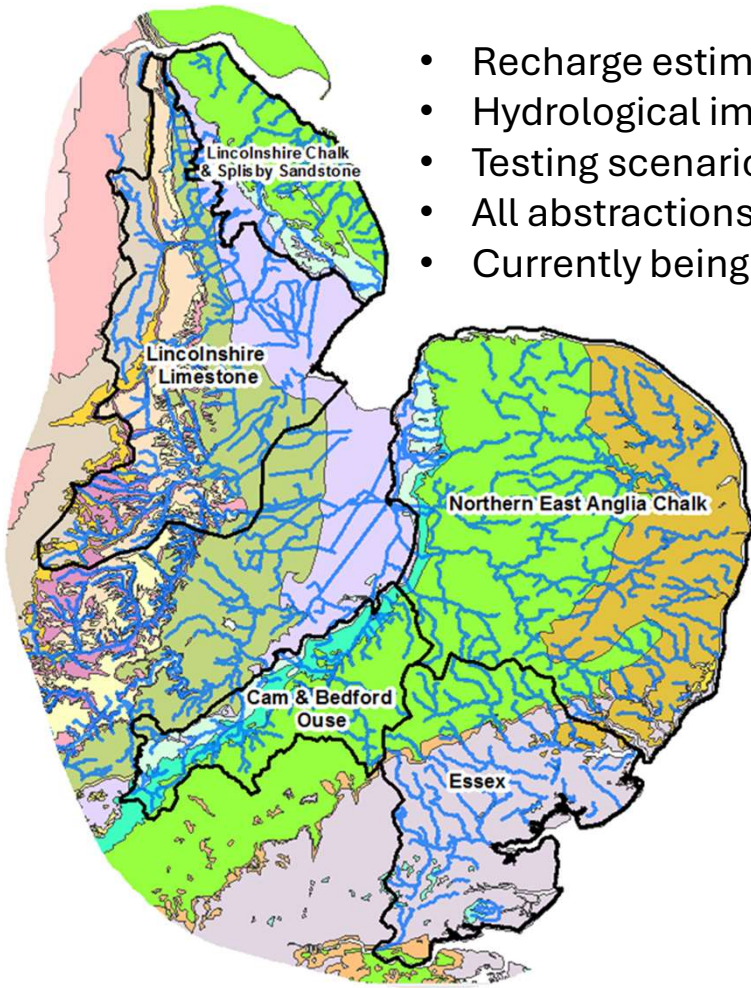


Dr Mark Grout will be talking
 GW augmentation schemes

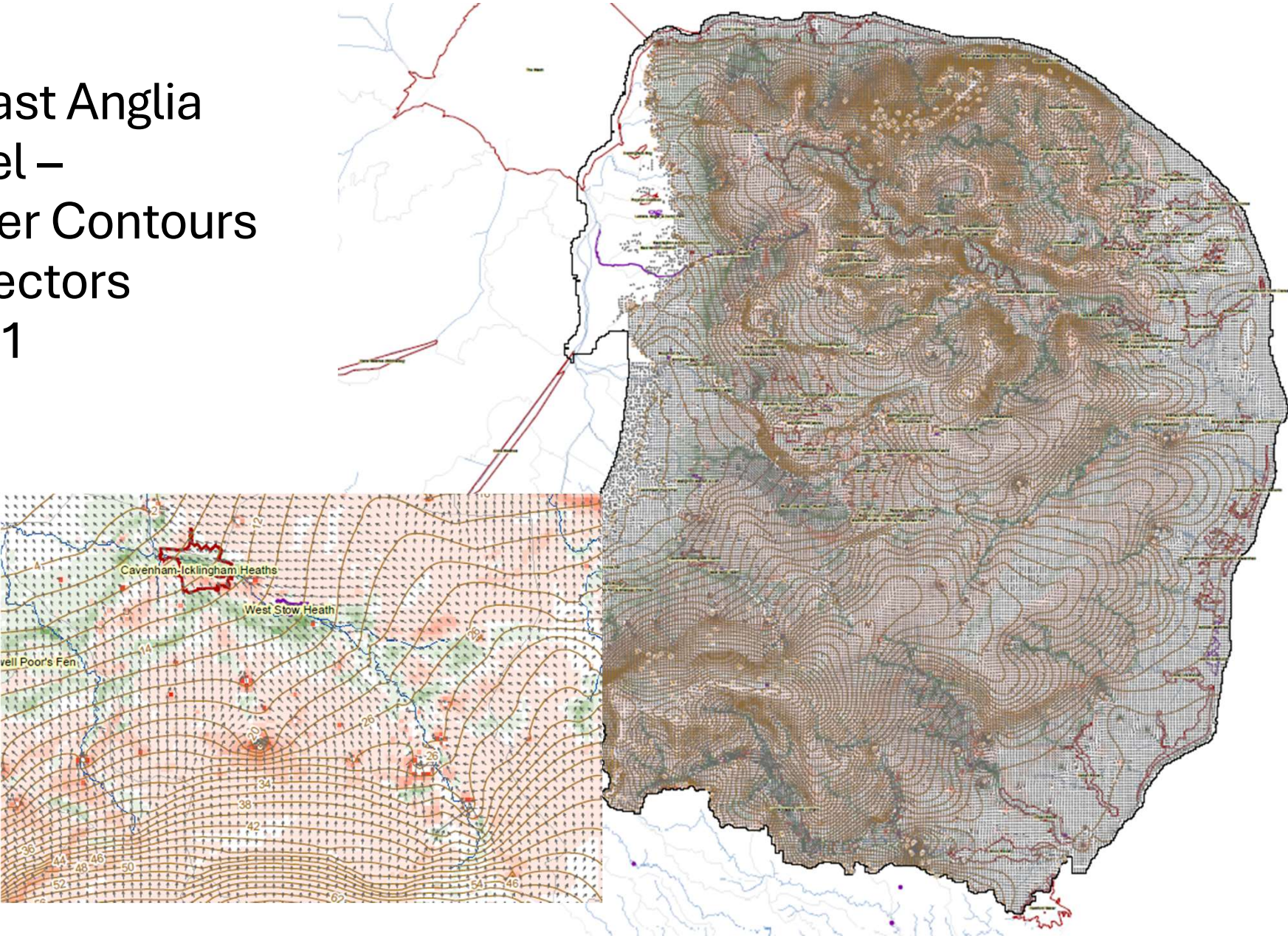


The 'Anglian Models'

- Recharge estimation
- Hydrological impacts of abstraction
- Testing scenarios/options appraisal
- All abstractions, all water features
- Currently being updated

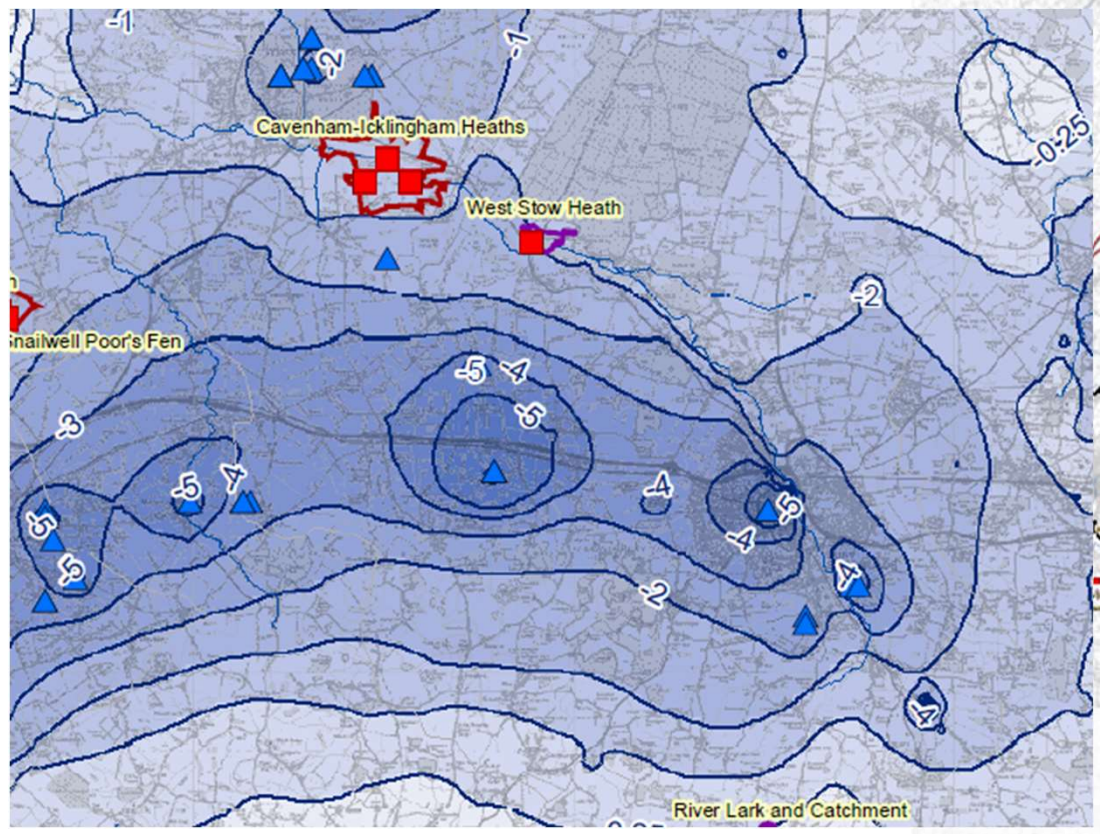
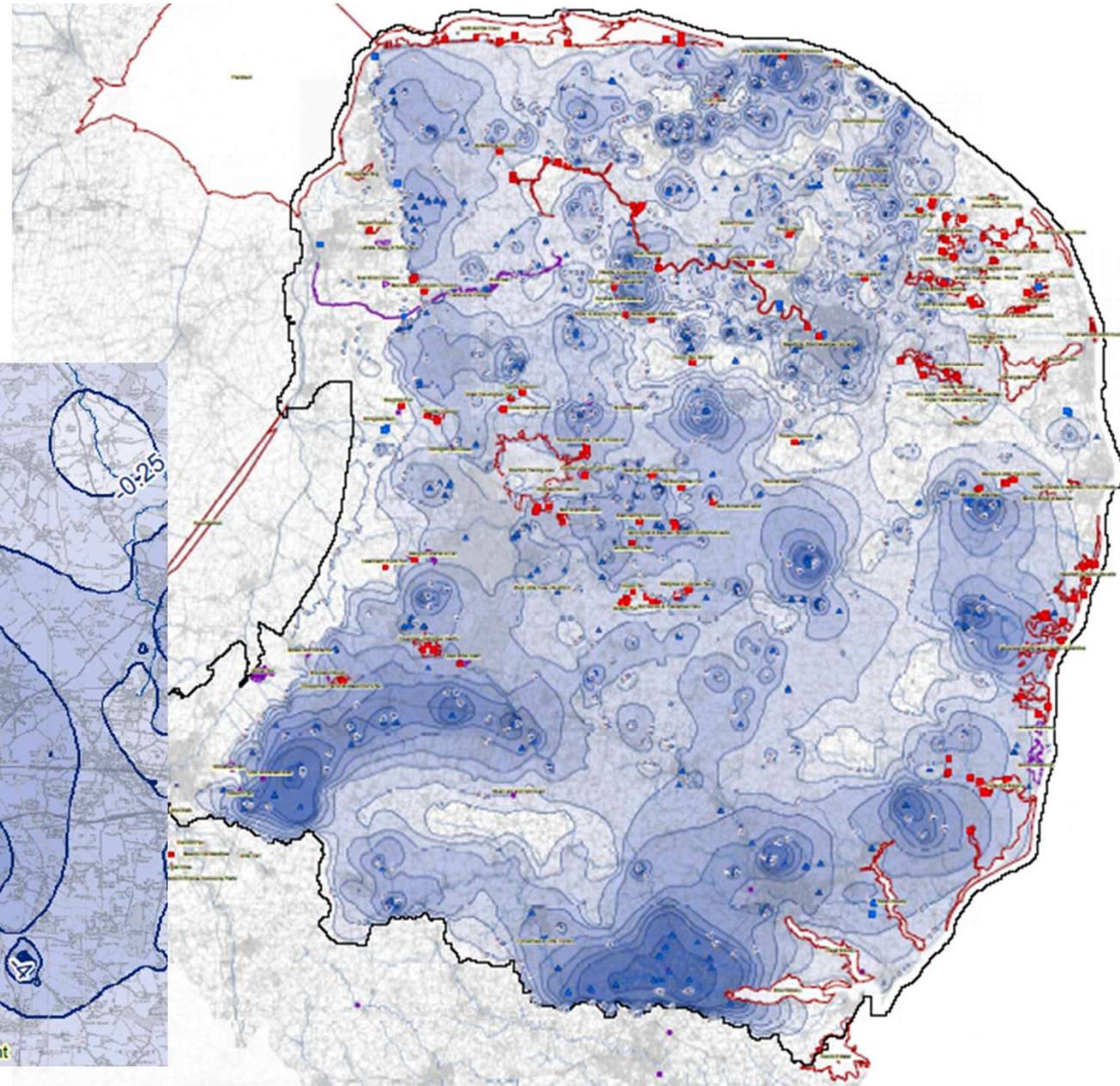


Northern East Anglia
Chalk Model –
Groundwater Contours
and Flow Vectors
August 1991



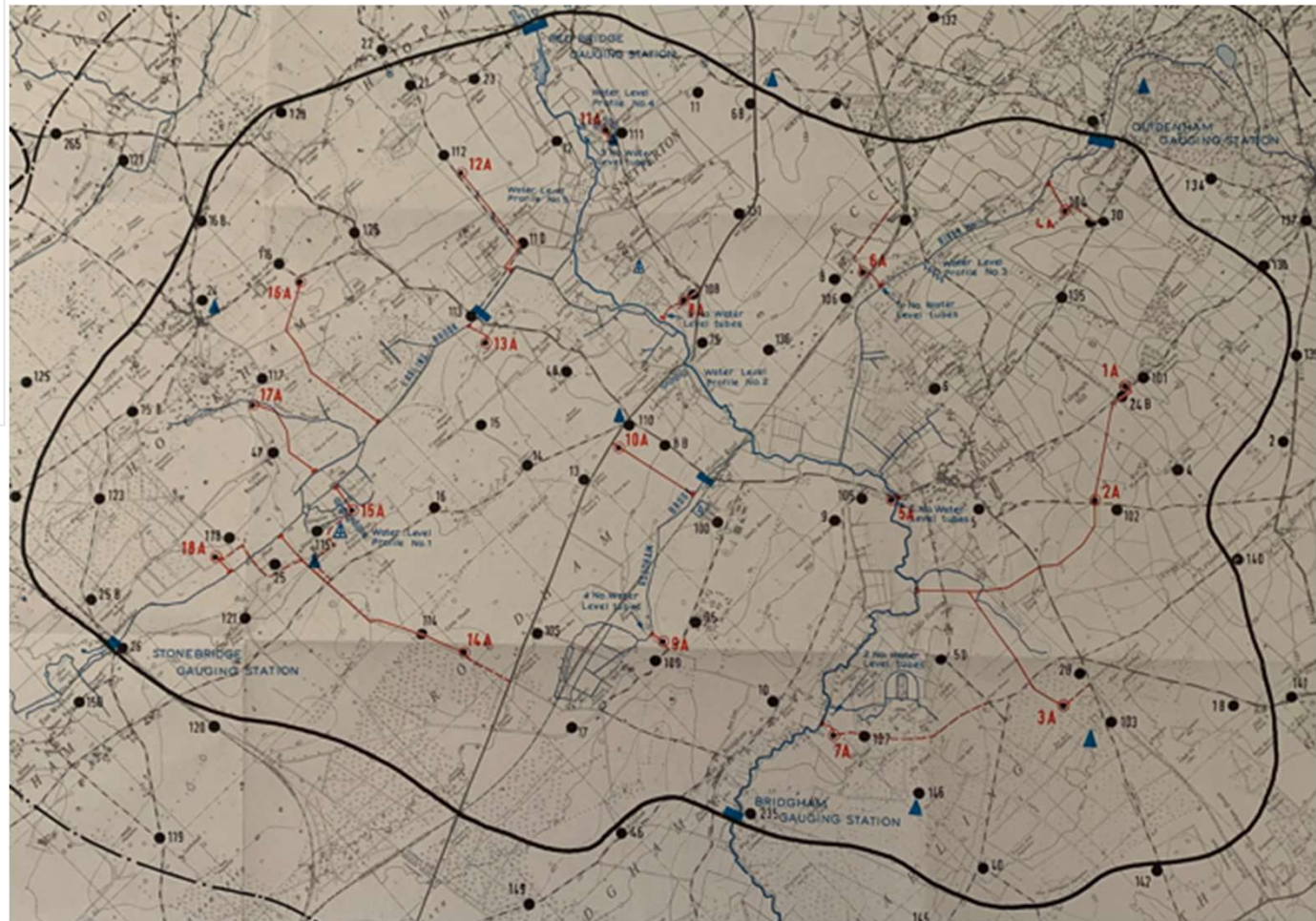
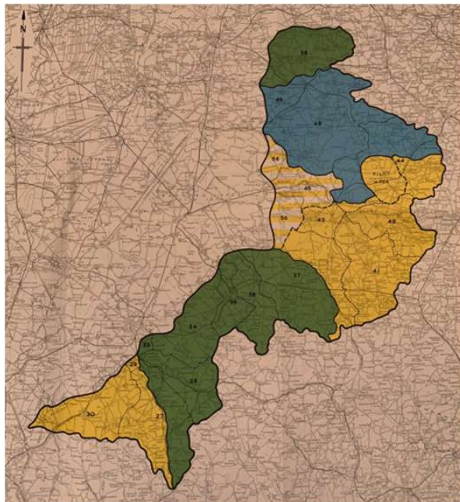
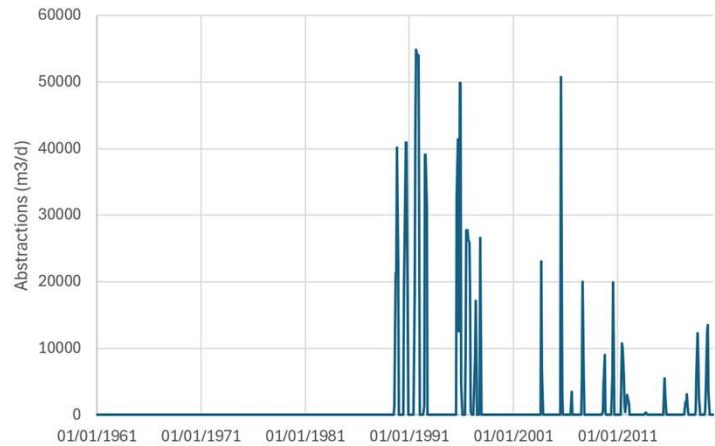
Chalk Drawdown August 1991

'In-combination' impact

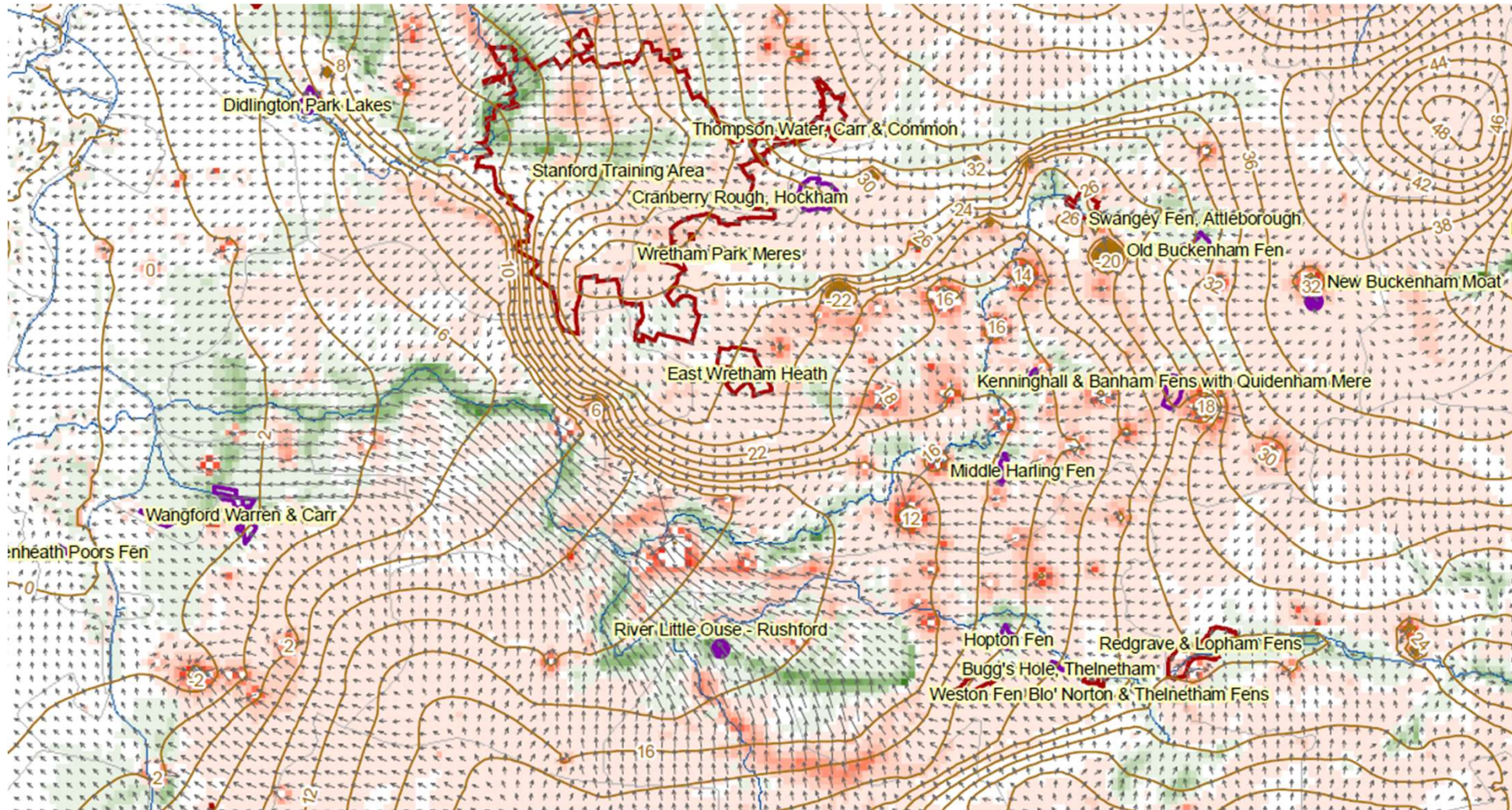


Great Ouse Groundwater Scheme Conjunctive Use - Supplement to EOTS

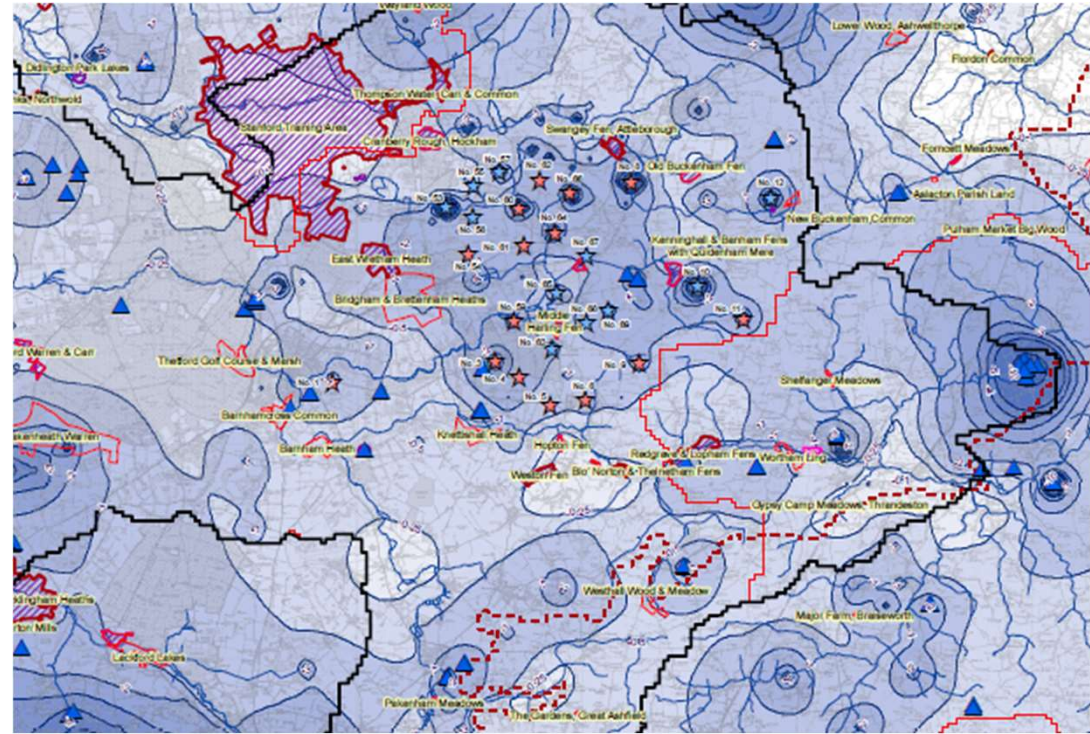
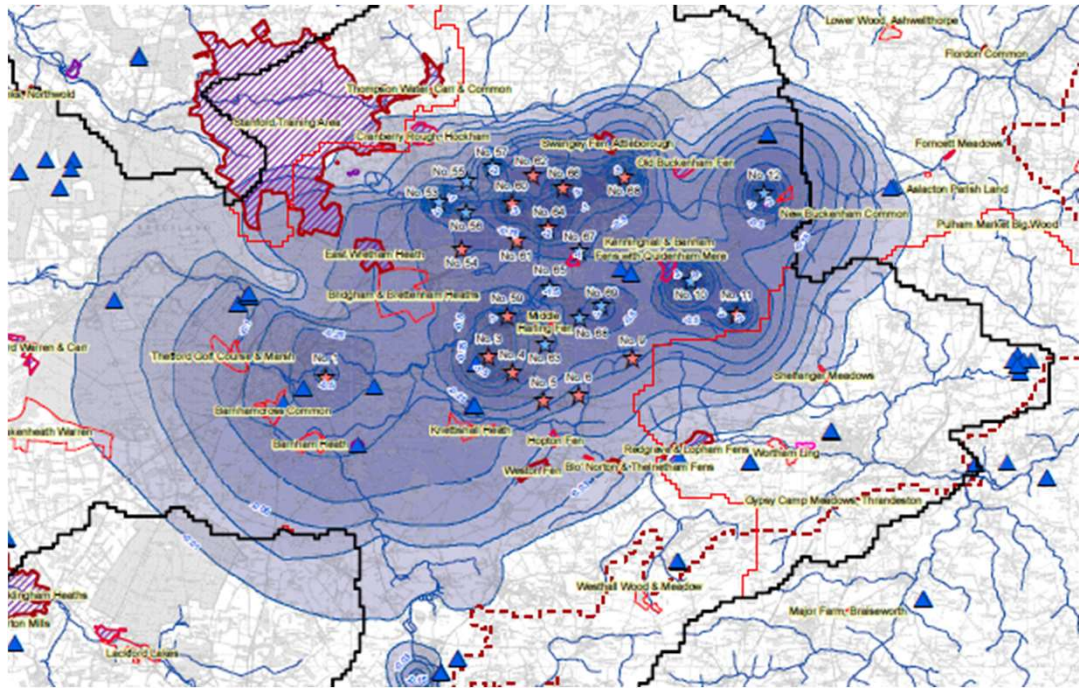
GOGS_Combined_Abstractions



Thet Catchment August 1991

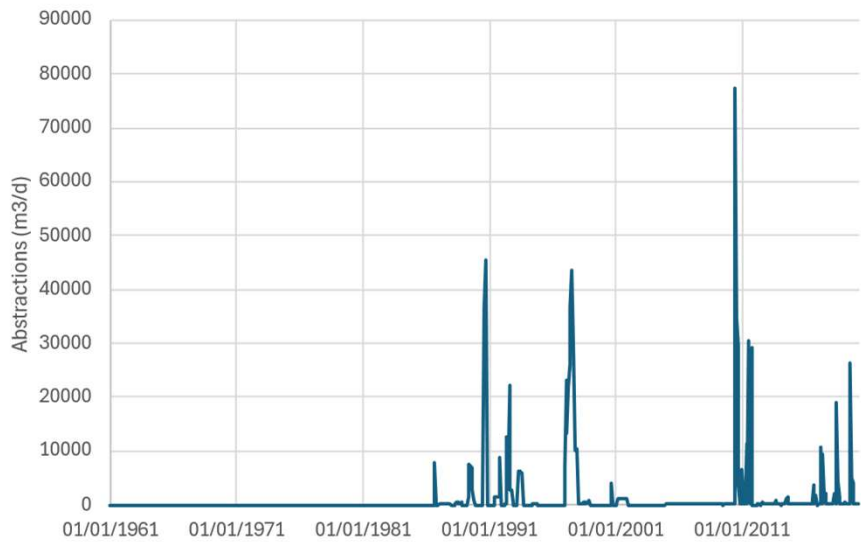


The Catchment August 1991

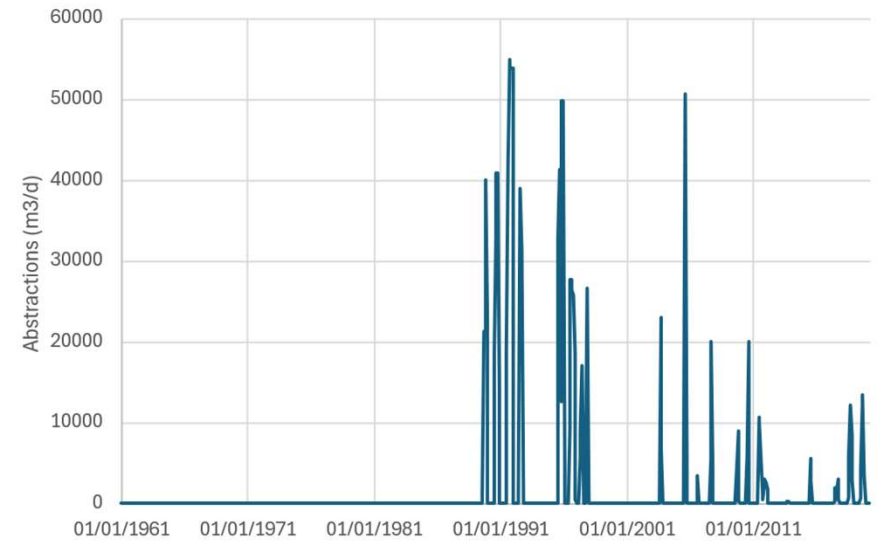


GOGS, SAGS, WAGS

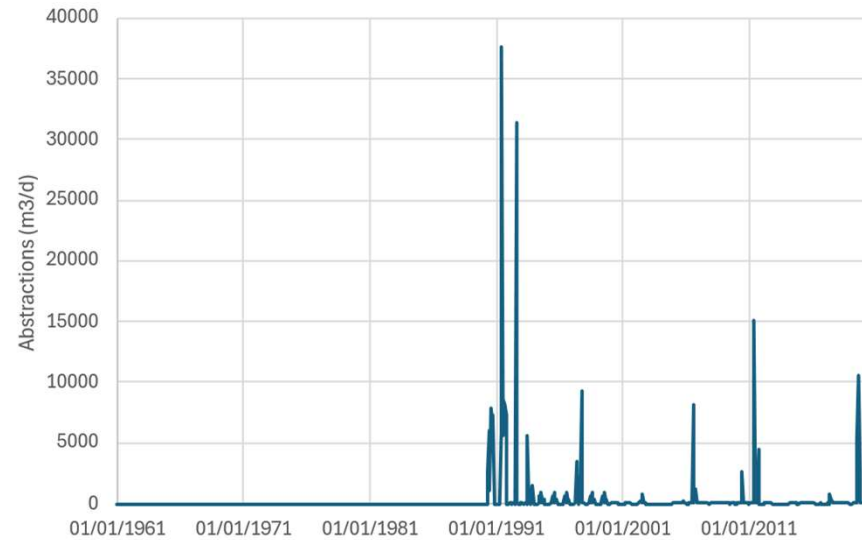
SAGS_Combined_Abstractions



GOGS_Combined_Abstractions

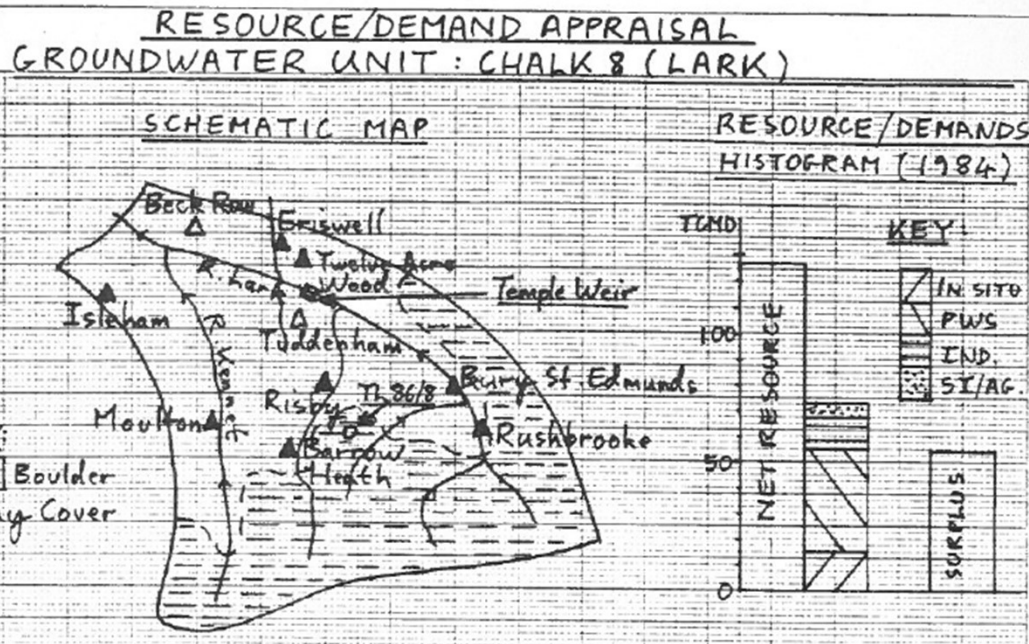


WAGS_Combined_Abstractions



Cambridge Water Plan programme

Emphasis shifted to 'river support'
 River support embedded in the water resources development plan for the Great Ouse Chalk



GROUND - WATER UNIT	Y E A R					
	1985	1990	1995	2000	2005	2010
CHALK 1	HS	SR,OR				
CHALK 2		HS LM SR,OR			lvel	
CHALK 3	RST			Rhee		
CHALK 4	RSC	OR		Cam		
CHALK 5 & 6	DM SR		LR,OR		Granta	
CHALK 7	DM SR			LR	Lodes	
CHALK 8	LM LR,SR		DM?			
CHALK 9	HA LR				LM SR,OR	Little Ouse
CHALK 10	LM OR			SR LR		
CHALK 11	LM SR,OR		LR,OR,SR			
CHALK 12	LM SR				DM	
CHALK 13	OR				DM	
CHALK 14					LR,SR	

KEY TO ABBREVIATIONS:

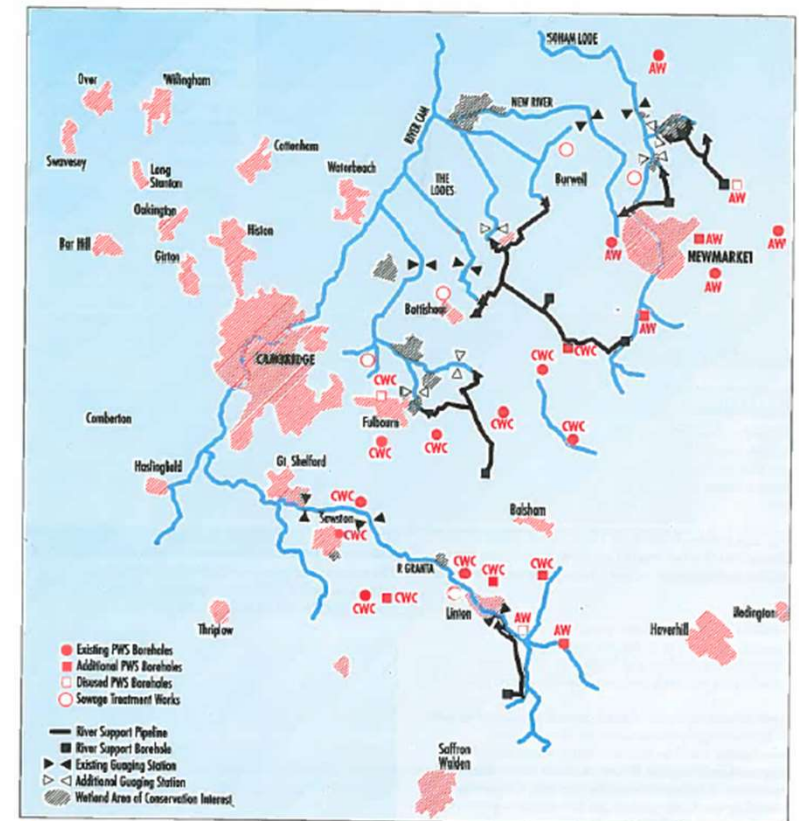
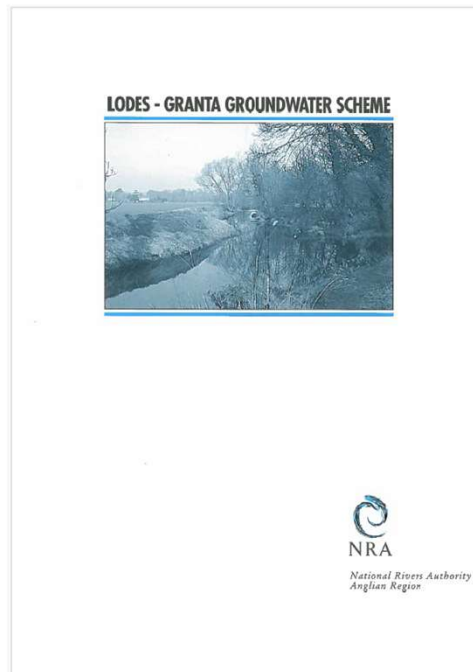
- HS : Hydrometric Survey
- RST : River Support Trial
- HA : Hydrogeological Appraisal
- LR : Licence Review
- LM : Lumped Parameter Model
- SR : SRO Review
- DM : Distributed Parameter Model
- OR : ORO Review
- RSC : River Support (Design & Construction)

Groundwater Augmentation to Provide Environmental Protection - Lodes-Granta 'River Support' Scheme

- Followed on from the Rhee Scheme
- Regional groundwater model late 1980s
- Construction early 1990s

There is an acceptable level of groundwater abstraction which can provide water for public supply* and, through augmentation, ensure an acceptable level of hydrological impact at water features.

* Up to 50% Long Term Average Recharge?



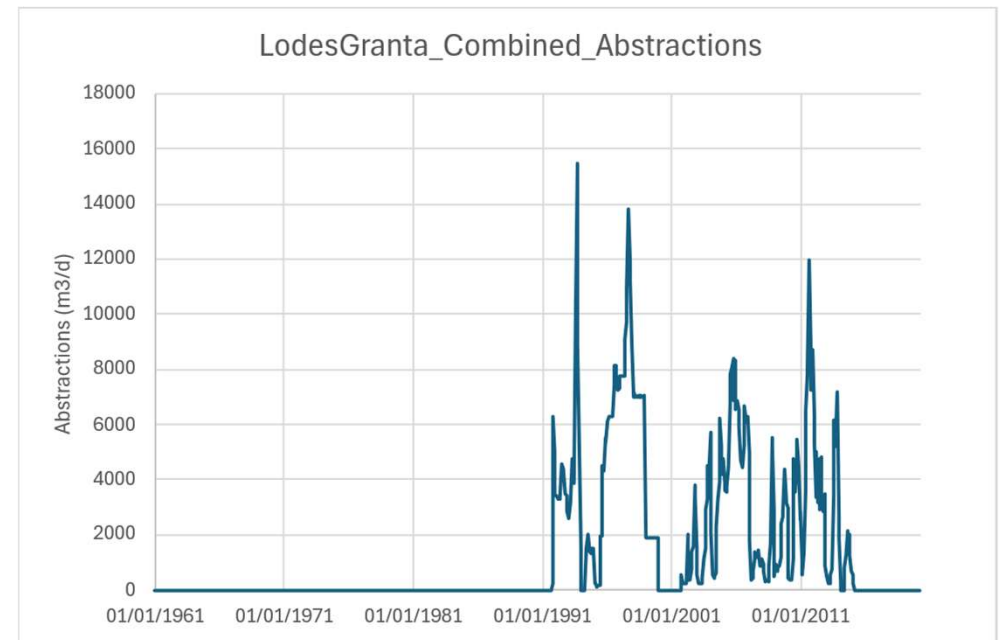
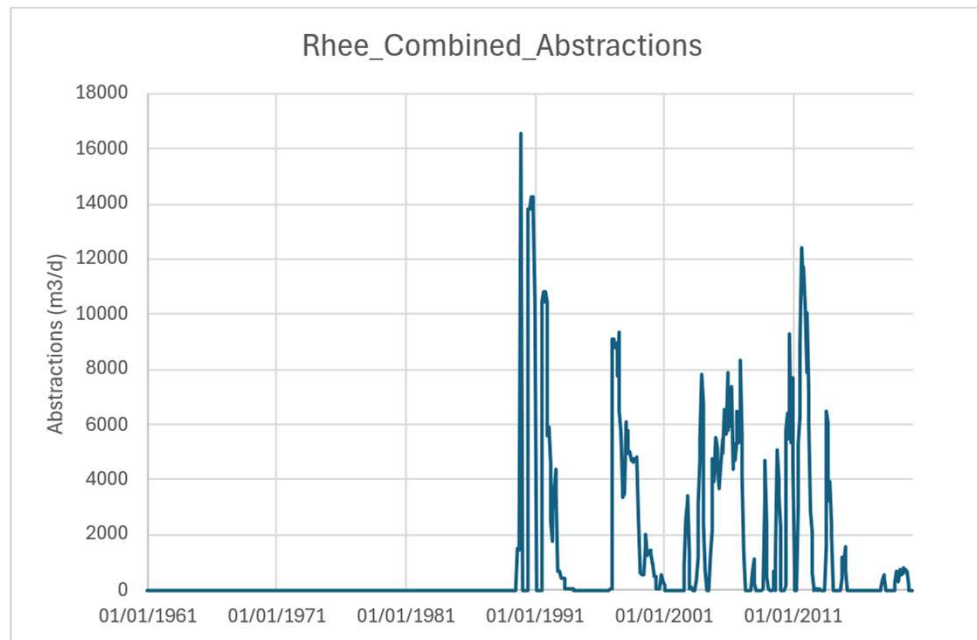
Management - the scheme ensures that the needs of the whole of the water environment are taken into account and that a balance is maintained between the level of abstraction and the conservation of amenities.

Protection - this extends from the protection of sensitive areas such as Sites of Special Scientific Interest and the river environment to the maintenance of public water supplies.

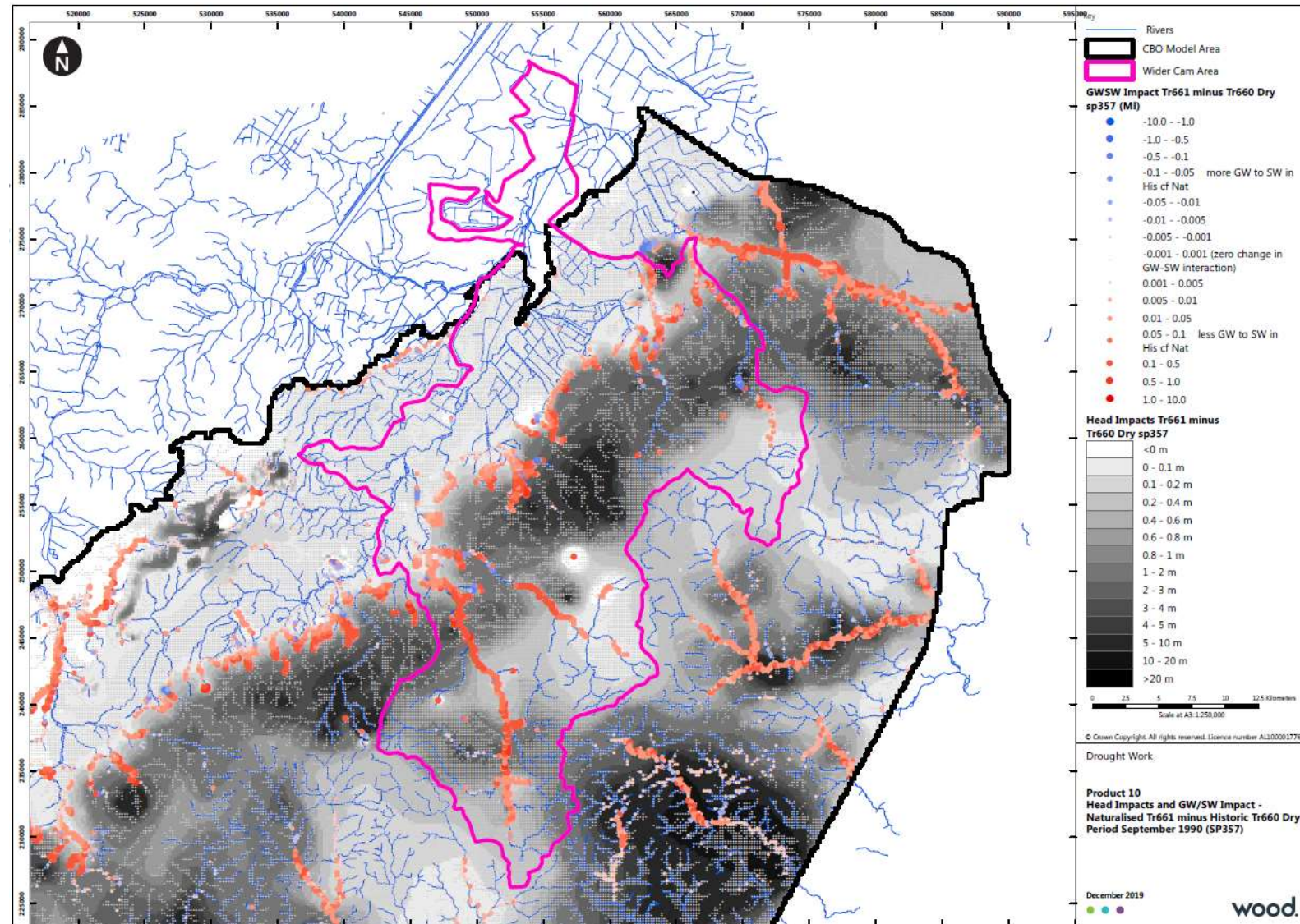
Improvements - these stem from enhanced flows in local rivers and watercourses with a consequent increase in river water quality.



Rhee, Lodes-Granta Groundwater Schemes



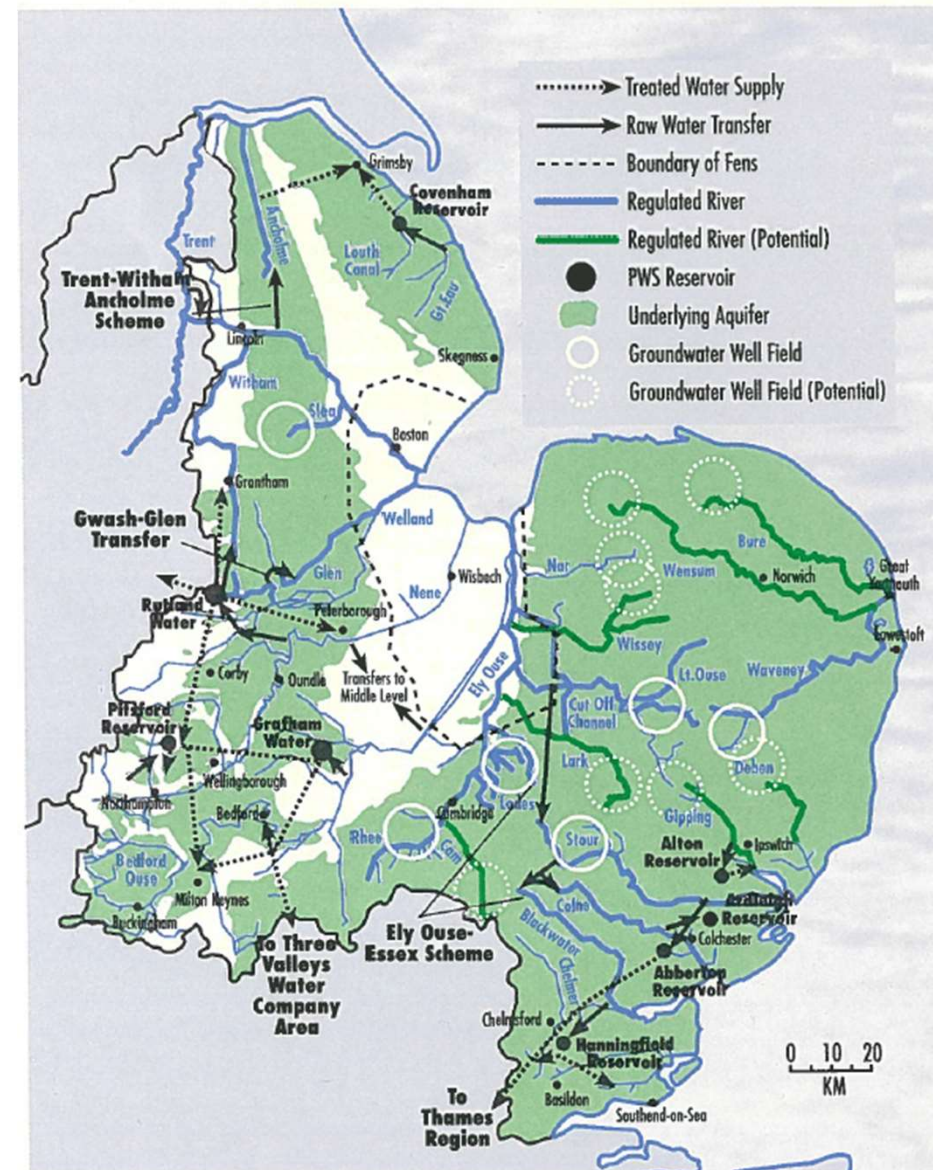
Chalk Drawdown and GW to SW Impacts – CBO Model



So...

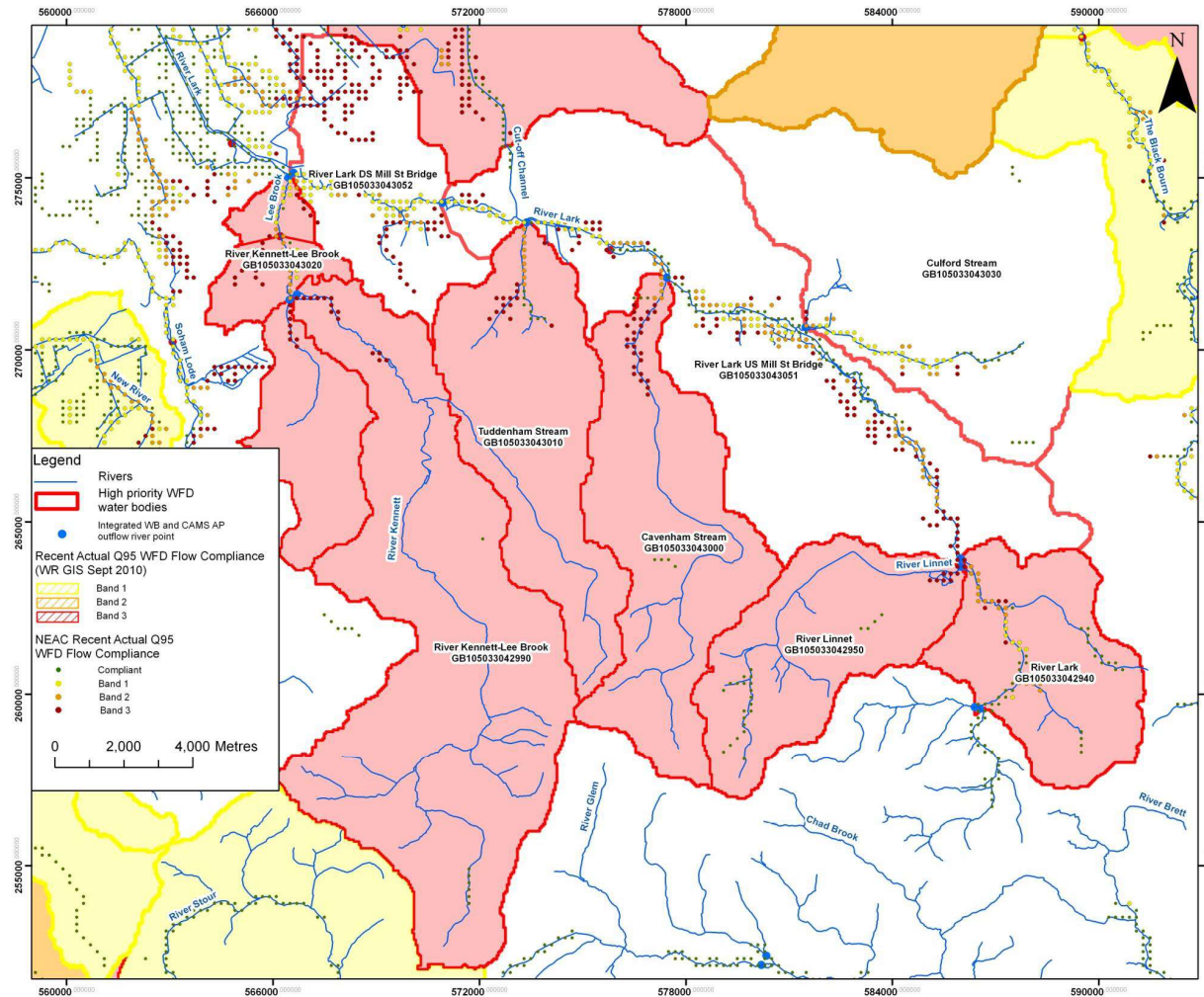
- Number of schemes
- Part of a regionally integrated water supply system
- Inter-basin transfer
- All used through droughts
- Still in operation

Figure 1 - Major Elements of Regional Water Resource System



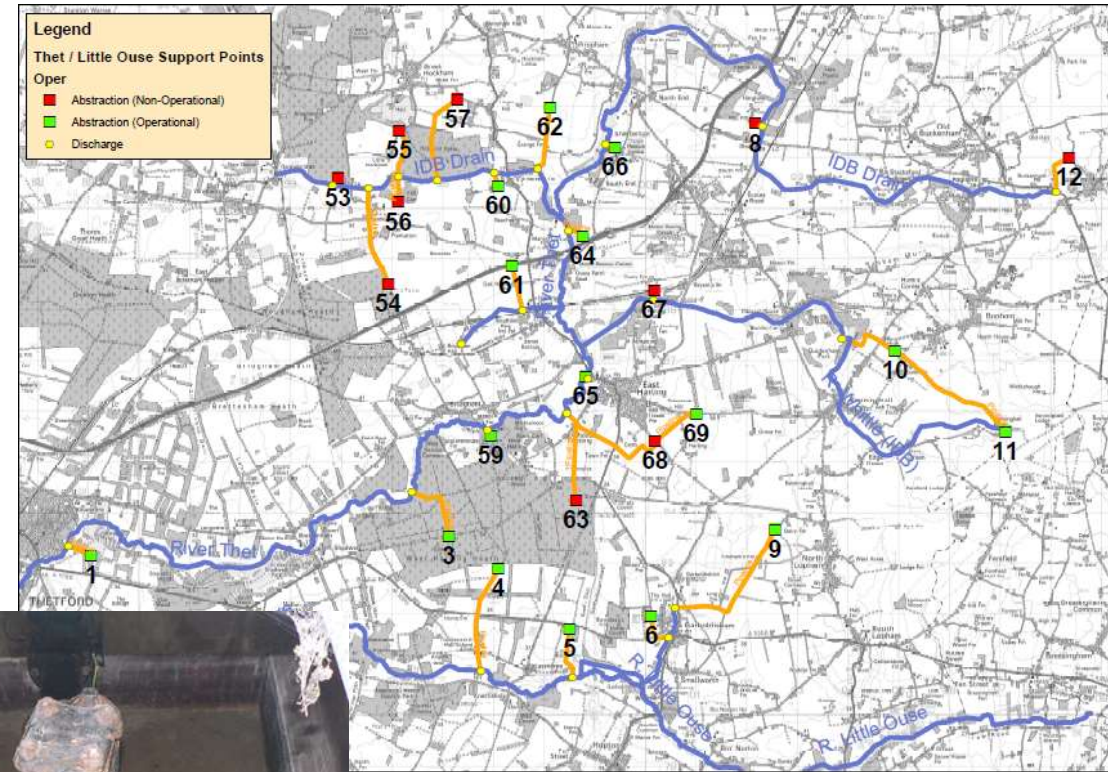
Early 1990s onwards – change of approach

- DoE did not support further development of the GOGS scheme
- Philosophy of river support has survived but as mitigation provided by abstractors
- Continued momentum from WFD measures/options:
 - Abstraction reduction
 - River support
 - Channel morphology adjustment
 - Disproportionate Cost test



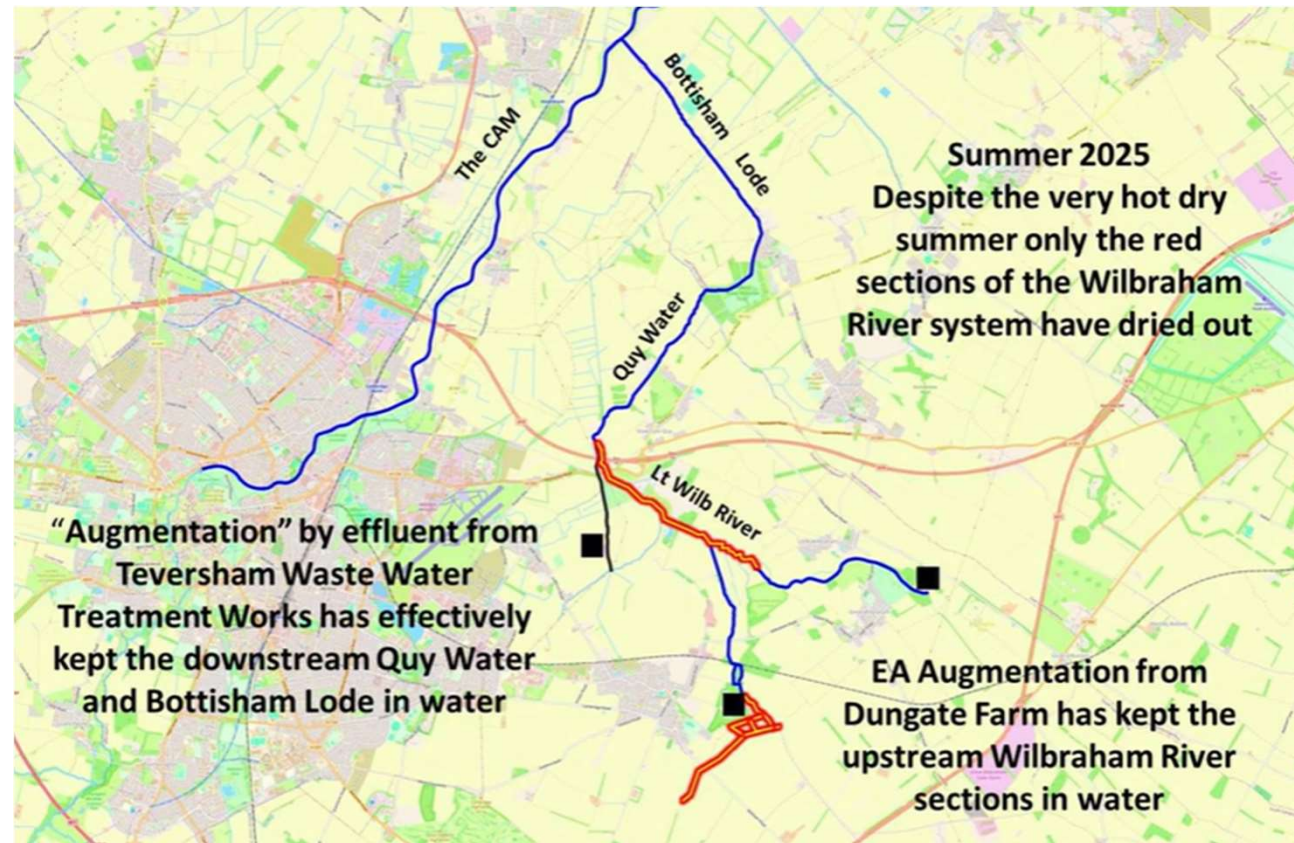
Challenges – asset performance

- Costly to construct and test
- Power lines, boreholes, pumps, headworks, pipelines, outfall works
- Abstraction boreholes not remote from streams
- Maintenance of an intermittently used asset – revenue funding pressures
- Flowmeters on abstraction and discharge points
- Records management, corporate memory
- Inflexible operation
- VKD in the Chalk
- Net Gain?



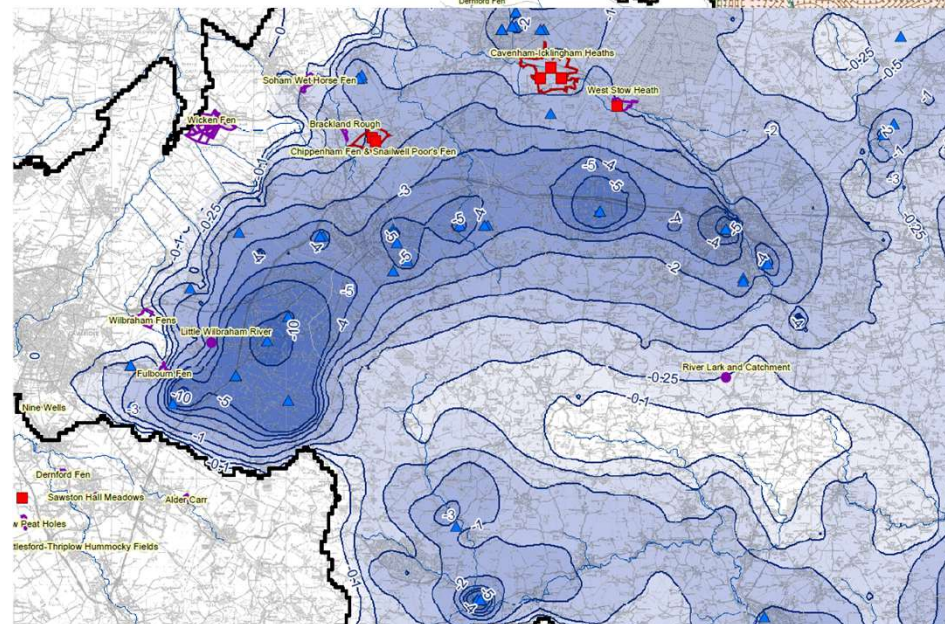
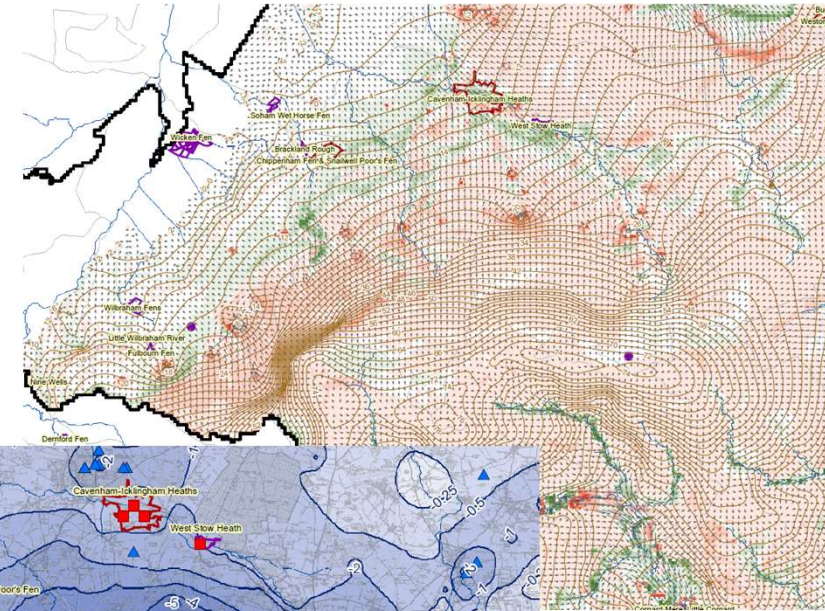
Challenges – Environmental Support

- Limitations with design approach
- Not working as intended
- Long term adjustment in water table
- Public Expectation
- Drone survey 2025
- Changing environmental standards



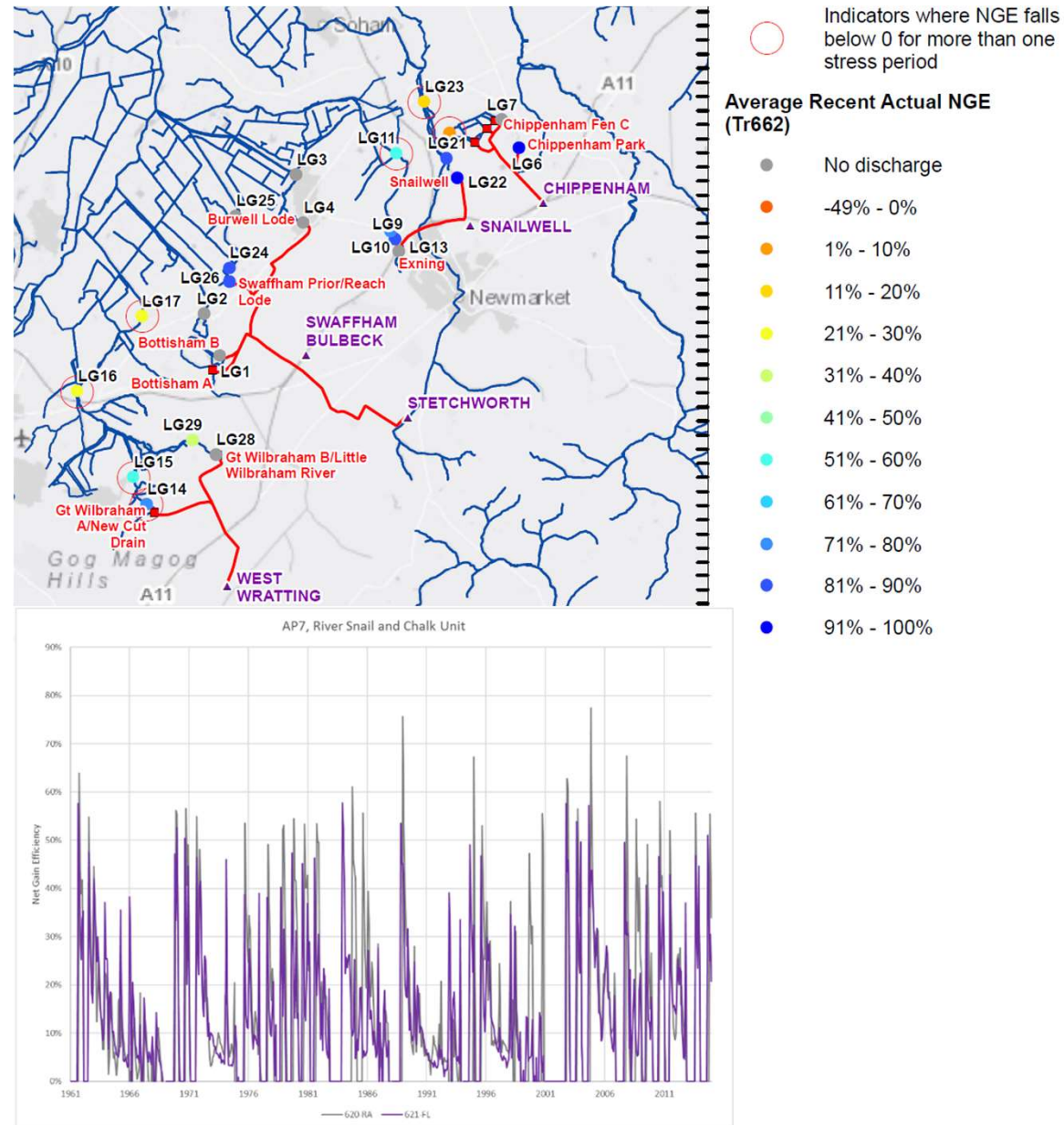
Review of the Groundwater Augmentation Assets

- Models offer the opportunity to review schemes
- Models used to help design some schemes but much simpler
- GOGS – electric analogue
- WAGS - ?
- SAGS – suck-it-and-see
- Rhee – ‘Explicit’ formulation
- Lodes-Granta – drain cells



Review of the Groundwater Augmentation Assets

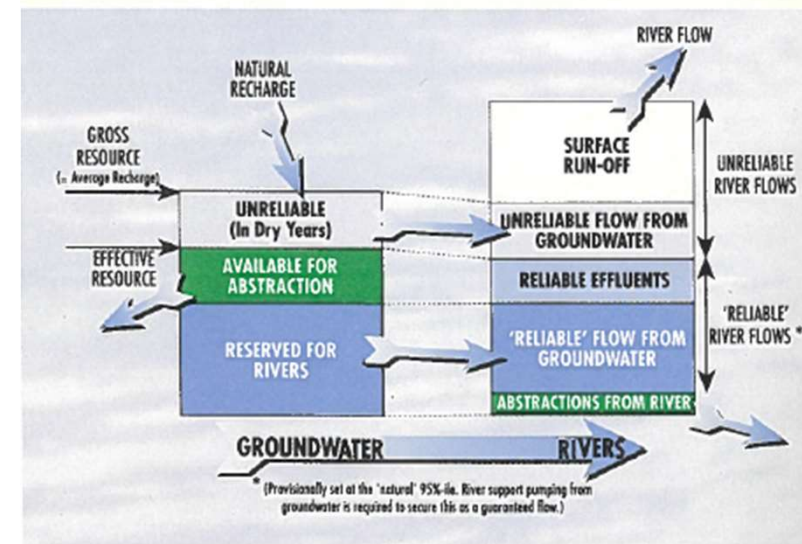
- Net Gain – long term:
 - WAGS 80%
 - GOGS 50%
 - SAGS 20%
- Function of time, distance downstream, receiving/non-receiving
- Overtaken by new developments – repurposing
- Licence optimisation
- Rhee, Lodes-Granta, some negative net gains
- Changing environmental standards
- **Are they ‘sustainable’?**



Previous Criteria for Defining 'Available Resource'

- Section 14 Surveys
- Cambridge Water Plan
- Anglian Region Water Resources Strategy 1994
- Groundwater Balances
- % of LTA Recharge
- >30/40% - River Support would be required

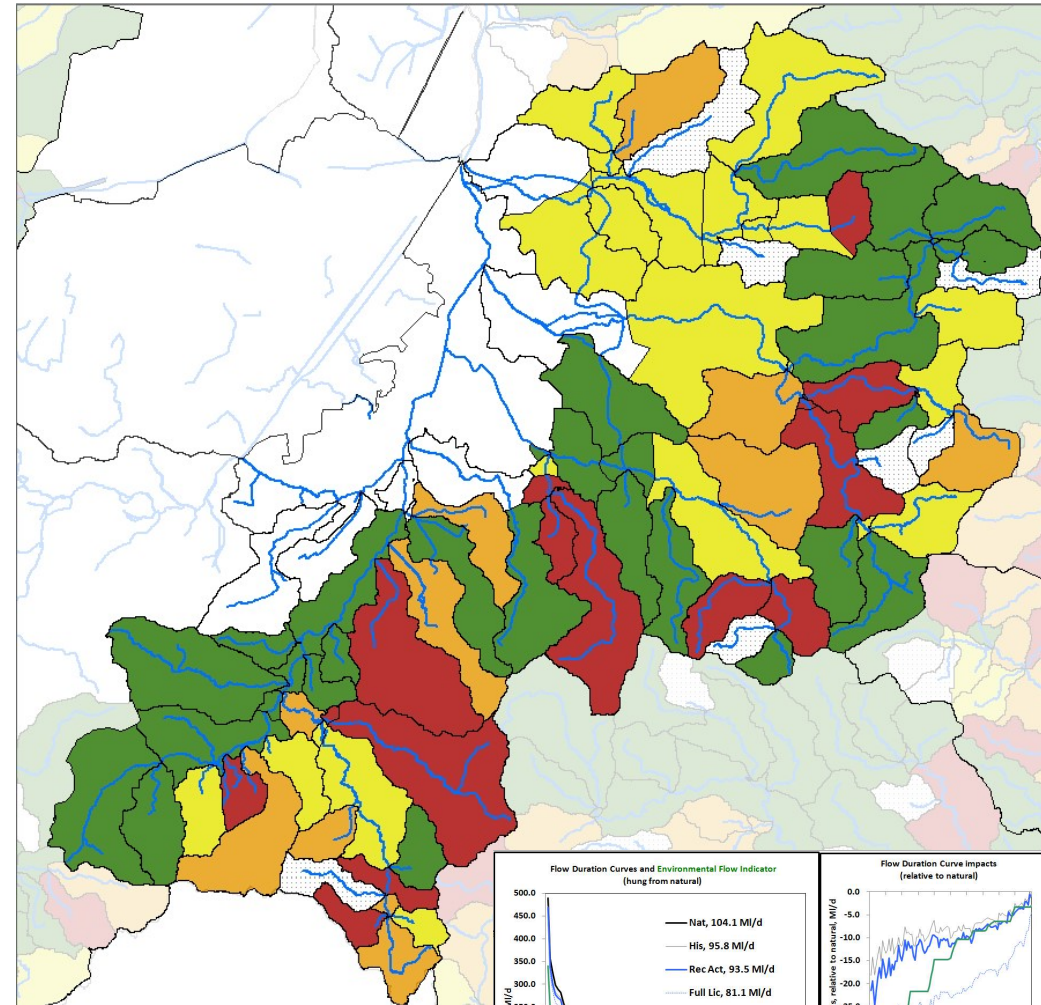
Figure A4.2 - The Allocation of Groundwater to Rivers



RESOURCES		Gross Resource	Effective Resource	RIVER NEED		ABSTRACTIONS AND NOMINAL SURPLUS					
Groundwater Unit and Catchment				Gross Environ. Allocation	Net Reliable Effluent minus Unconstrained Abstractions	Groundwater Allocation to River	Allocation with 50% of Gross Resource (changes)	Licensed Abstraction	Balance Nominally Available	Balance Nominally Available with Env. Limited to 50% Gross Resource (changes only)	
(1)		tcmd (2)	tcmd (3)	tcmd (4)	tcmd (5)	tcmd (6)	tcmd (7 = (4-6))	tcmd (8 = (5-6))	tcmd (9)	tcmd (10 = (7+9))	tcmd (11 = (8+9))
Combs. Chalk											
	Unit 1	35.0	28.0	8.8		13.8	.0		5.6	22.5	-4
	Unit 2	118.8	95.0	25.9		21.8	4.1		38.4	51.9	-4
	Unit 3	70.5	56.4	28.0		8.5	19.5		41.3	-4.4	
	Unit 4	65.5	52.4	21.3		50.6	.0		77.7	-25.3	-5
	Unit 5	33.4	26.7	5.5		2.2	3.3		16.8	5.7	
	Unit 6	2.9	2.3	.8		-.1	.9		.2	1.2	
	Unit 7	84.9	67.9	21.5		8.6	12.9		57.3	-2.3	
	Unit 8	159.4	127.5	62.2		15.3	46.9		83.1	-2.5	
	Unit 9	263.4	210.8	144.7	131.7	11.8	132.9	119.9	81.5	-3.6	9.4
	Unit 10	177.7	142.1	78.8		3.9	75.0		44.9	22.3	
	Unit 11	87.4	69.9	42.8		.6	42.2		28.9	-1.2	
	Unit 12	72.5	58.0	33.2		.3	32.8		21.9	3.3	
	Unit 13	27.8	22.3	2.1		.0	2.1		5.3	14.9	

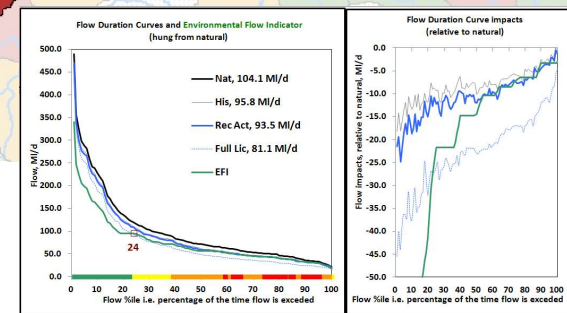
Current Criteria for Environmental Acceptability

- WFD Surface Water and Groundwater Tests to be met
- Protected Water Features – Rivers, Lakes, GWDTEs, Estuaries
- Effects on ecology acceptable – duty to achieve Good Ecological Status (GES)
- Hydrological impacts acceptable – all PWFs, all Abstractions
- Acceptable level of abstraction



Surface Water Body Recent Actual low flow compliance

- COMPLIANT
- BAND1
- BAND2
- BAND3
- Q95N < 20m³/d

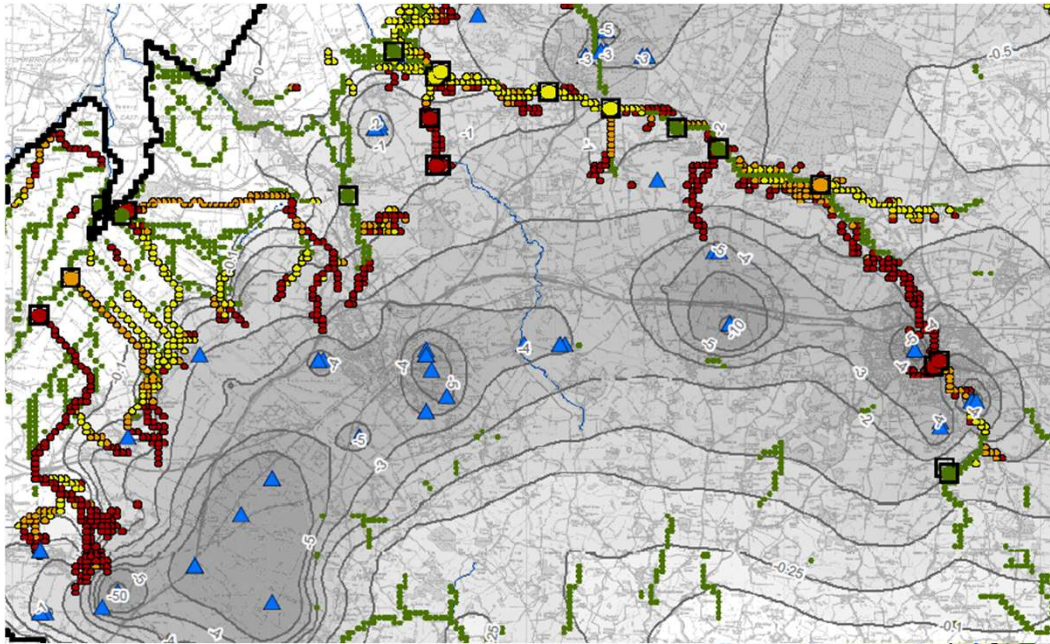


Sustainable Abstraction - ALFs Onwards

- Alleviation of Low Flow Schemes – Top 40 – Ver, Darent – Granta, Lark – 1990s
- Habitats Directive RoC – 2000-2010
- Restoring Sustainable Abstraction – 1997 – 2014
- Ant Broads and Marshes/Broads SAC - ongoing
- Water Framework Directive – 2010 onwards
- Water Company WINEP – AMP6 onwards
- Abstraction Licensing/CAMS CED



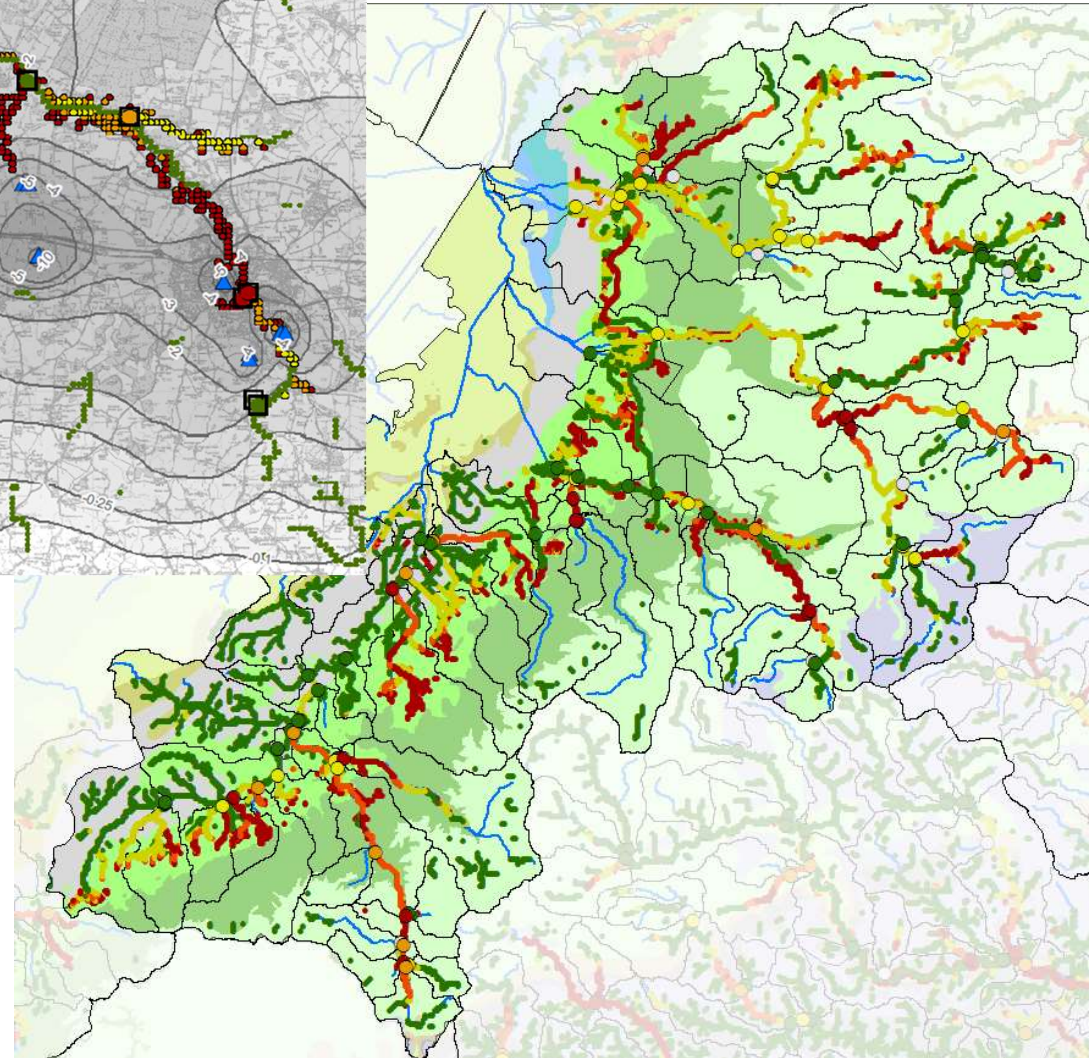
Chalk Streams



Meeting the EFI (ASB3) at the natural perennial head of Chalk Streams – Point X

Or the original springhead?

All abstractions impact all water features



**Surface Water Body
Sub-catchments and
outflow point Recent
Actual low flow
compliance**

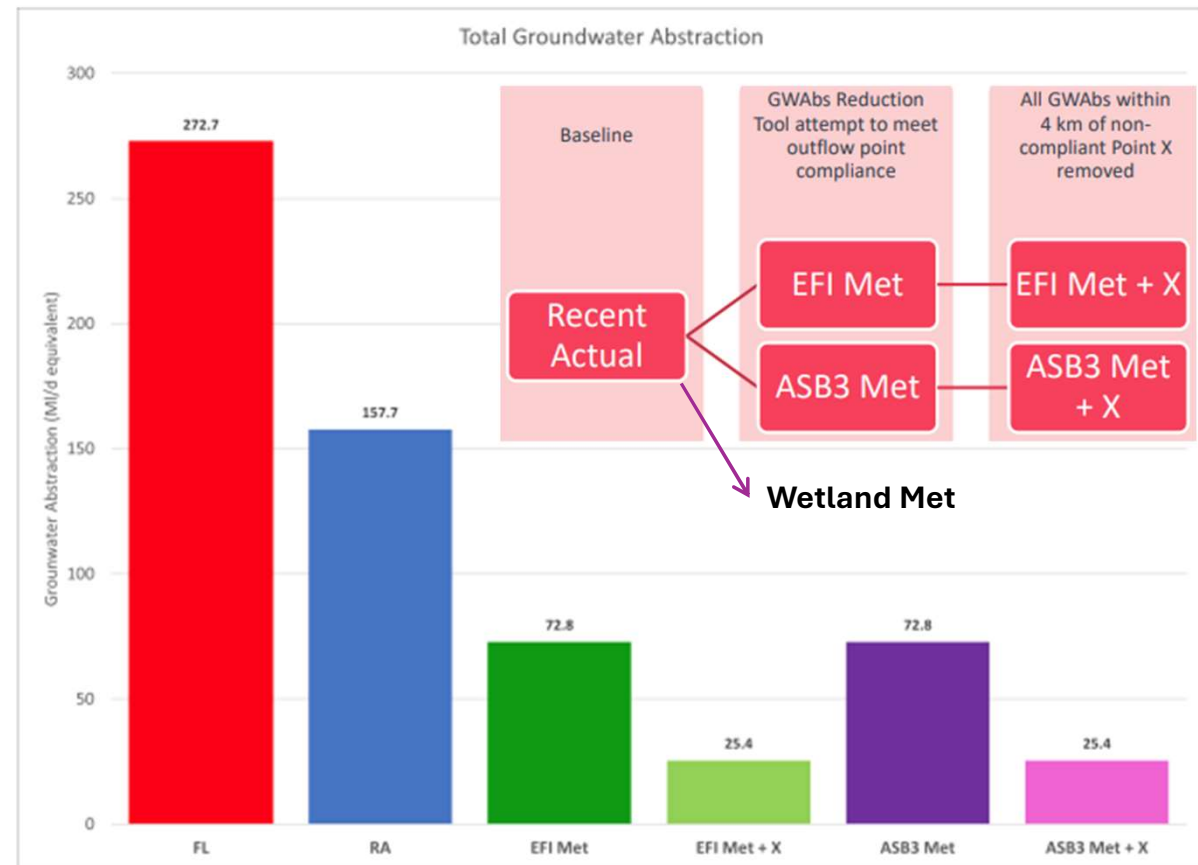
- COMPLIANT
- BAND1 NON-COMPLIANT
- BAND2 NON-COMPLIANT
- BAND3 NON-COMPLIANT
- Q95N<20m³/d

**200m model
Stream cell
Recent Actual
low flow
compliance**

- COMPLIANT
- BAND1 NON-COMPLIANT
- BAND2 NON-COMPLIANT
- BAND3 NON-COMPLIANT
- Q95N<20m³/d

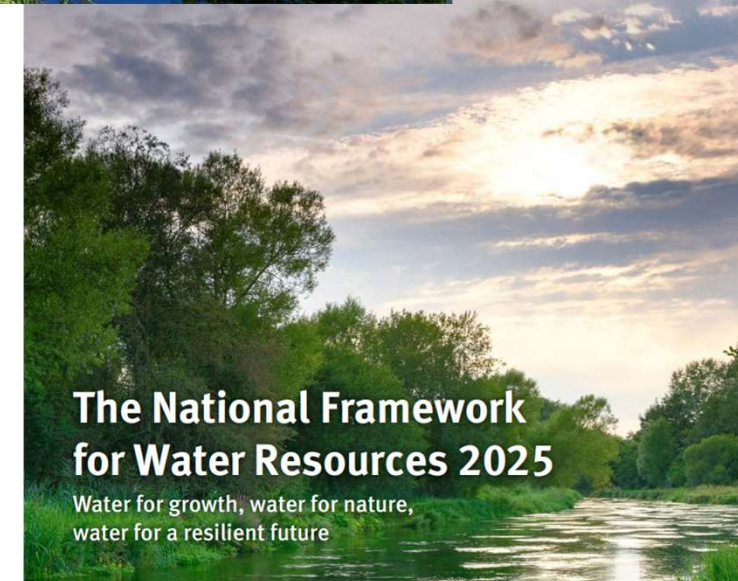
Sustainable Abstraction – More Recent Work

- Level of groundwater abstraction to allow:
- EFI to be met at all SWBs
- EFI or LFO to be met
- EFI to be met at natural perennial head of Chalk streams – Point X
- Support to National Framework 1
- Groundwater Abstraction <10% Long Term Average Recharge
- EFI to be met for all SWBs containing HD wetlands



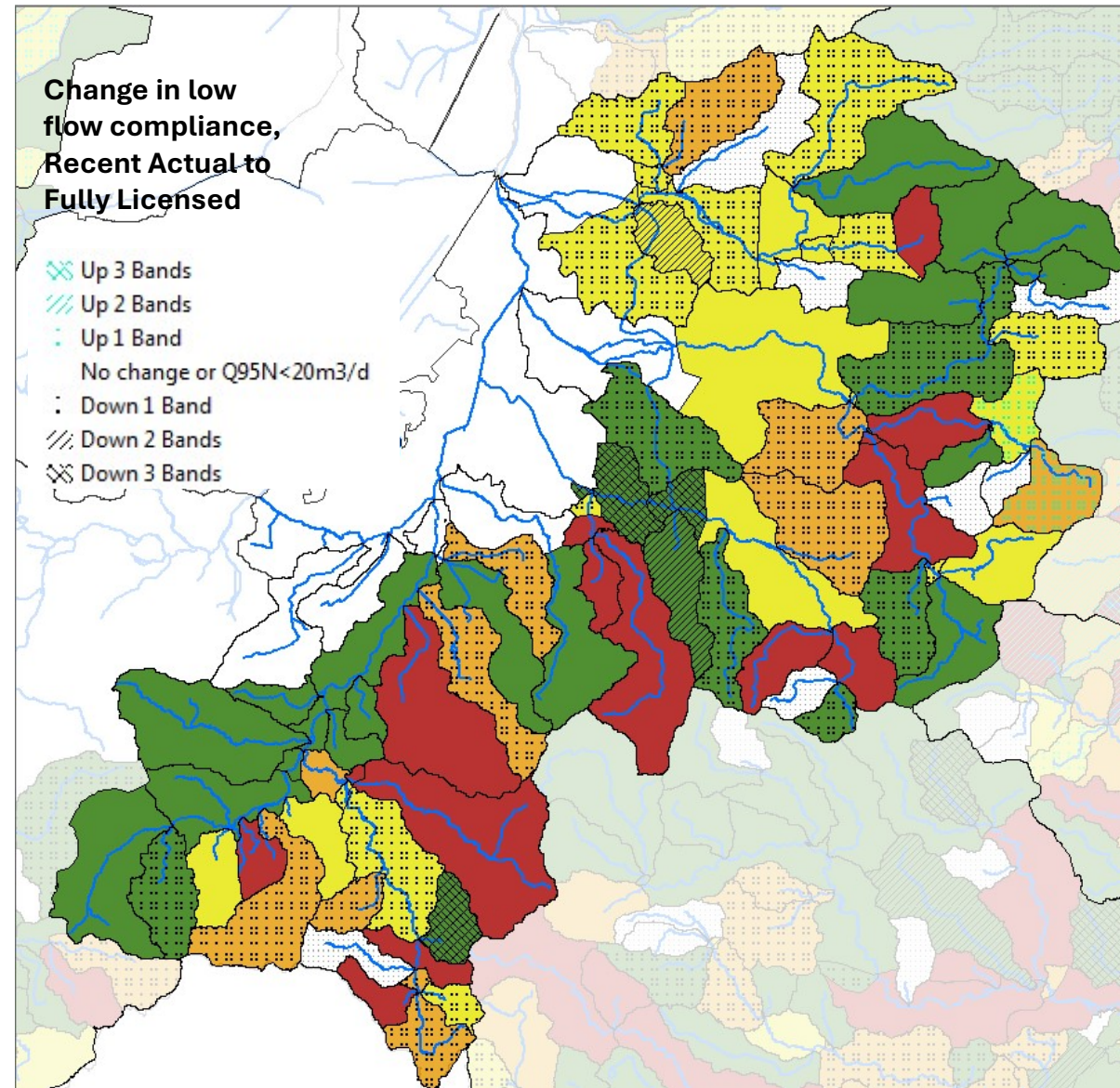
Current Direction

- National Framework 2/Environmental Destination – progression – RBMP not achieving GES
- Regional Group WRE
- Chalk Streams – flow targets upstream?
- Water Framework Directive
- Water Company AMP/WINEP
- New reservoirs – Lincolnshire plus Fens Reservoirs
- No Deterioration
- CAMS/CED and Catchment Permit Reviews – greater focus on wetlands



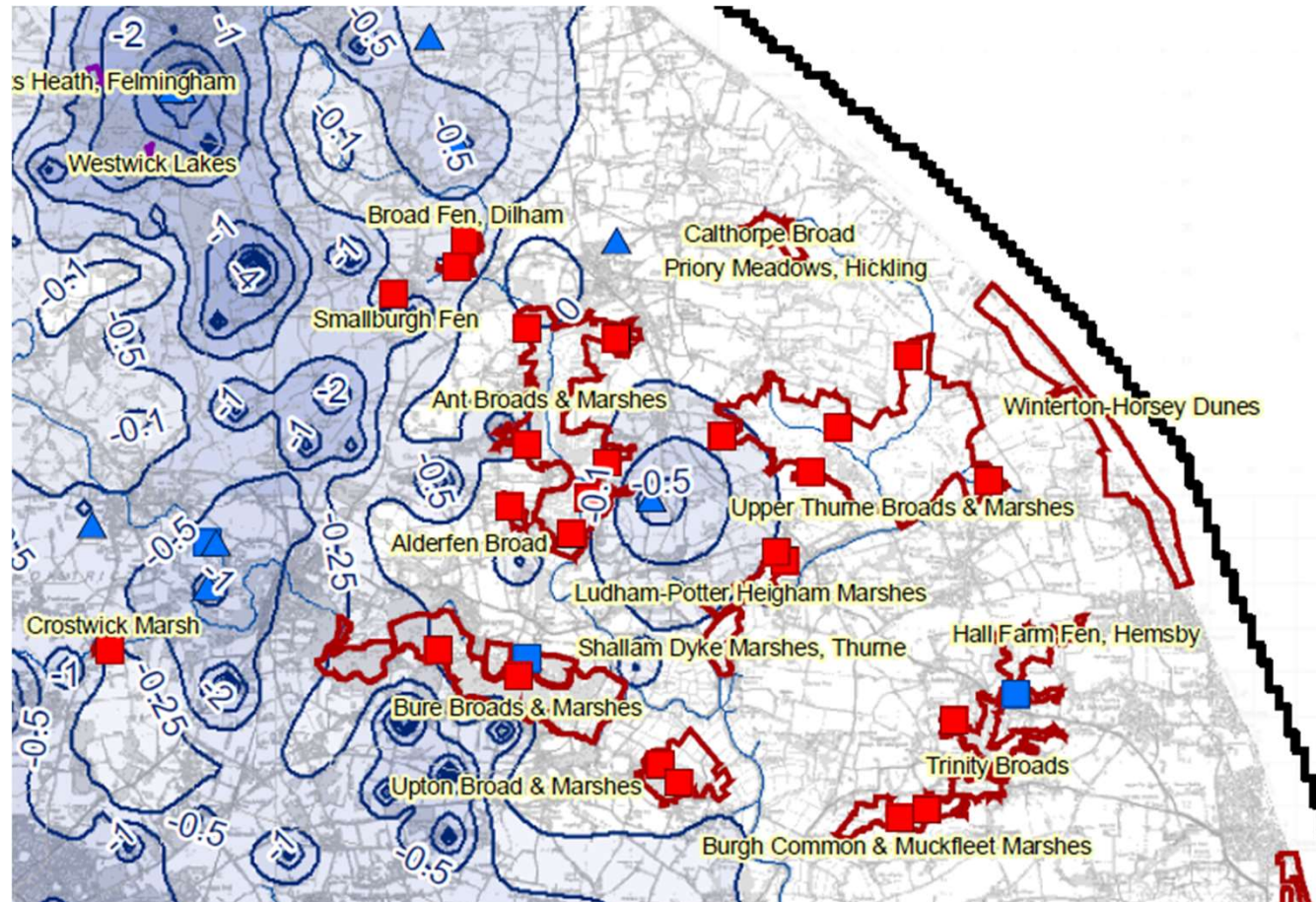
Risk of Deterioration

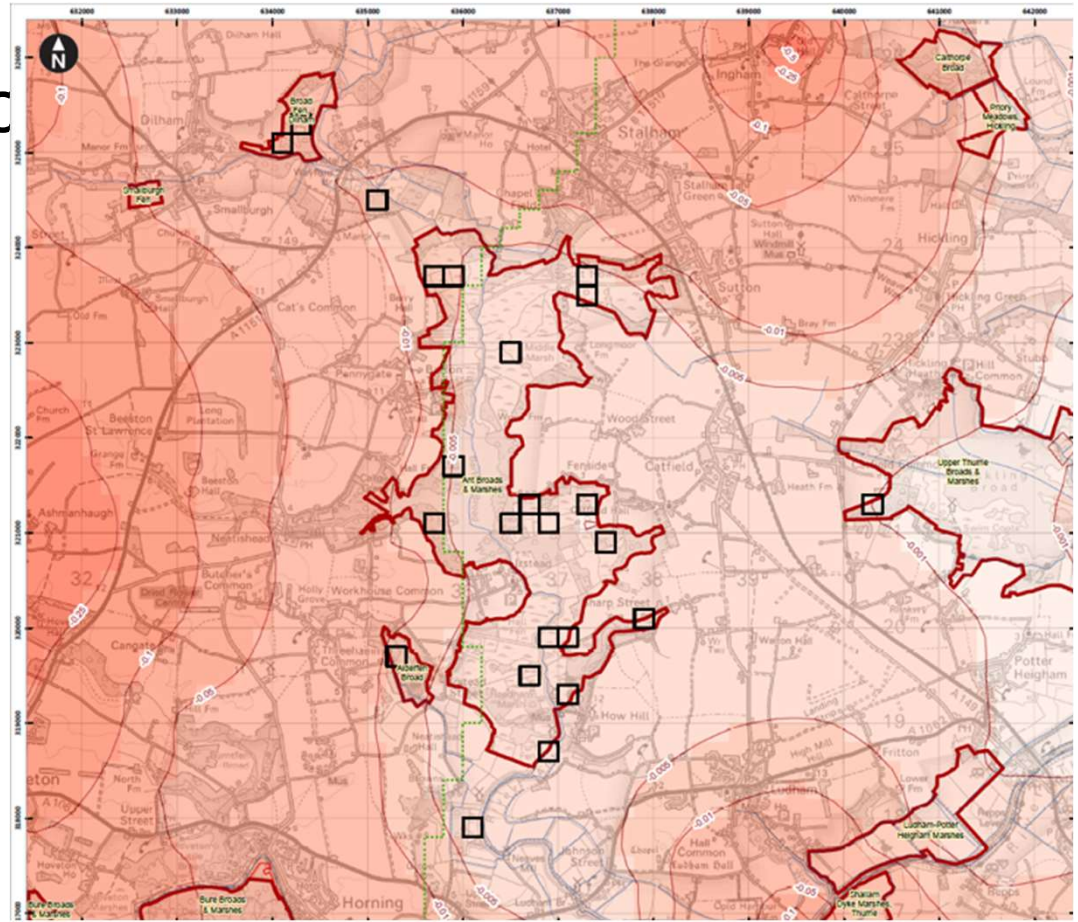
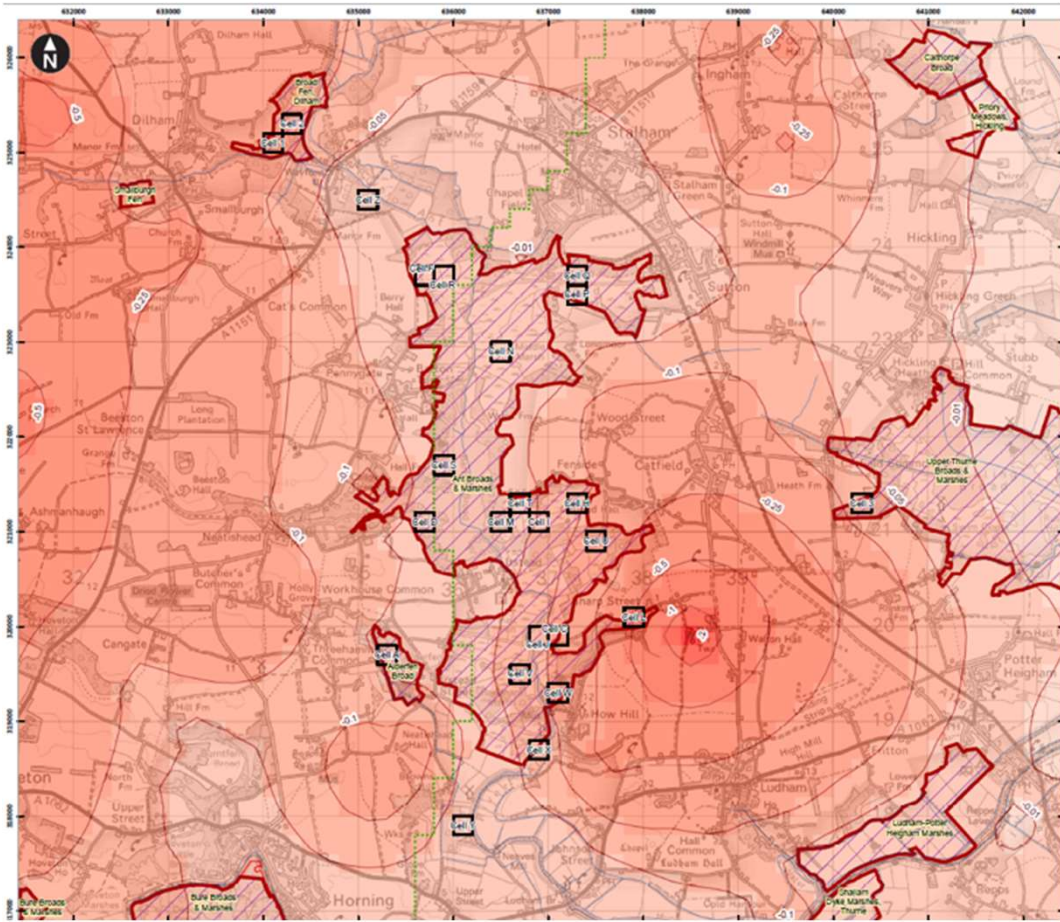
- Legal duty to No Deterioration – no cost-benefit
- Deterioration in flow
- Risk of Deterioration in ecology
- Licence caps with future start date linked to alternative supply



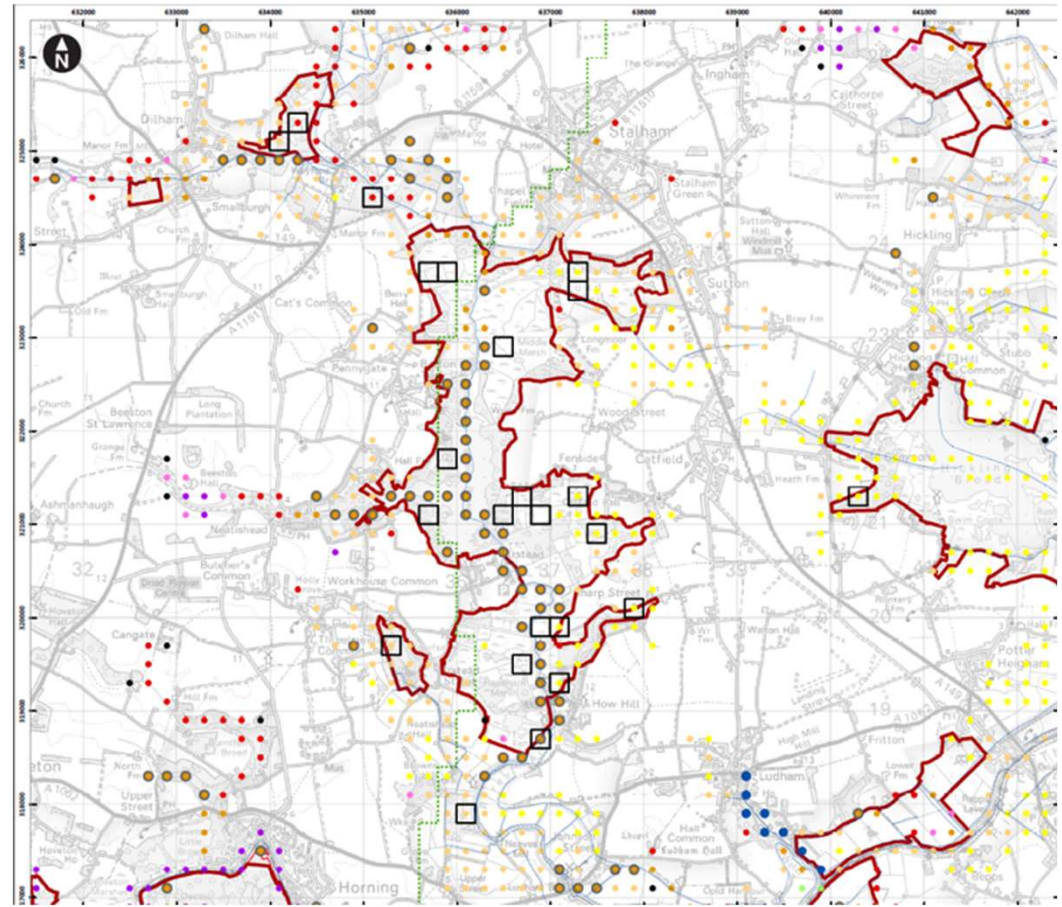
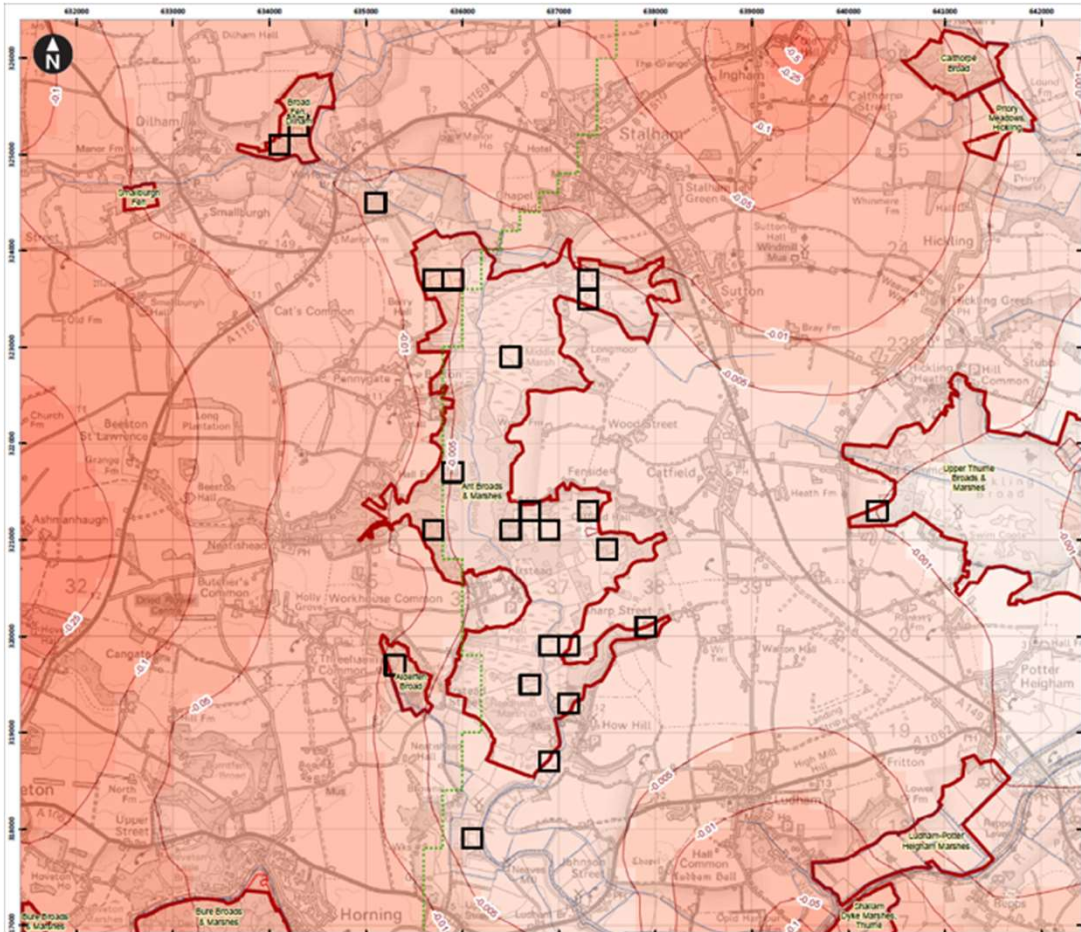
Wetlands

- Ant Broads and Marshes RSA Scheme
- ‘Flushing’ to be <5% change from Naturalised
- Extension to the Broads SAC
- Further extension across East Anglia?
- Level of groundwater abstraction based on 5% wetland criterion



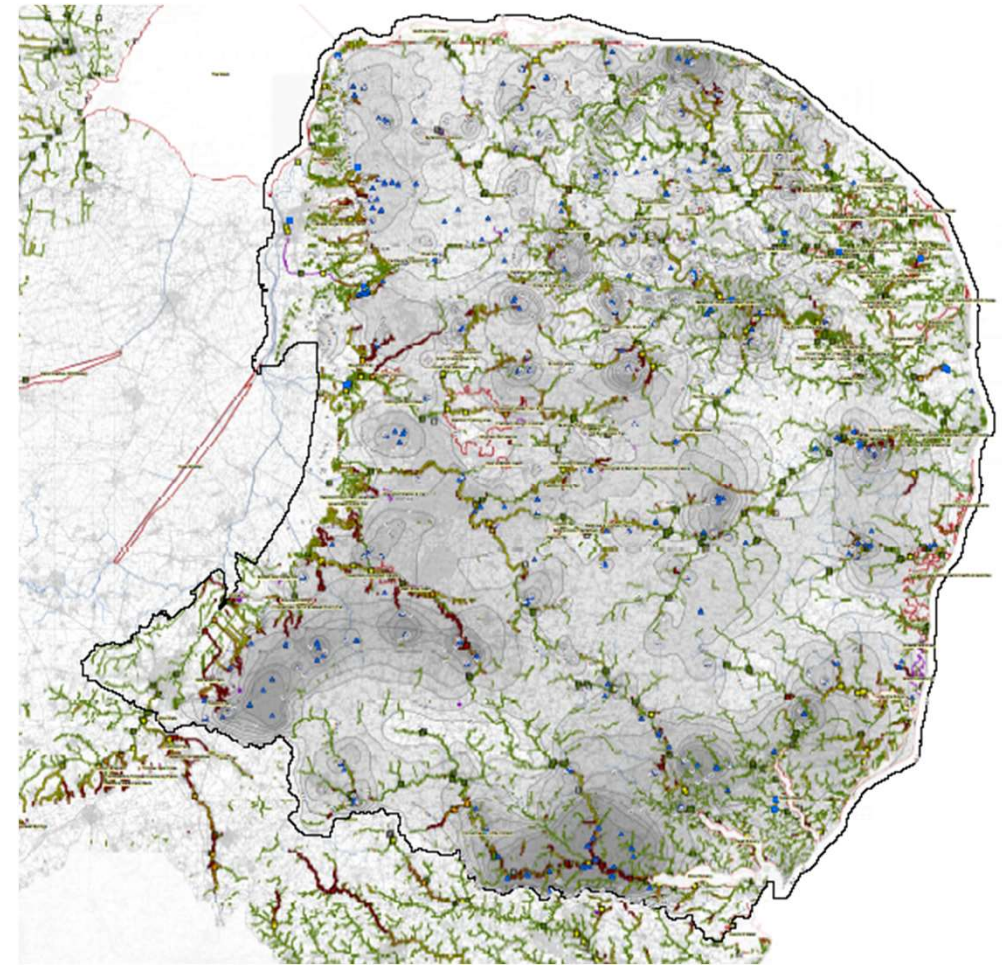


Sustainability of Rhee and Lodes-Granta Schemes



Quest for Sustainable Abstraction

- **Long Term** – meeting the EFI or a LFO – cost-benefit test?
- Darwin Green Decision – need for robust ecological evidence
- Pooled Hydroecological Modelling
- Habitats Directive wetlands – level of proof
- Agreement needed on allocation to the environment – acceptable levels of hydrological impact at all protected water features
- **Short to Medium Term** – Risk of Deterioration, Licence Caps, ‘Future Predicted’ abstraction
- Significant abstraction reduction – no river support
- Water Company Options Appraisal considering – new supplies, abstraction reduction, licence relocation, river support, hydroecology, conjunctive use, effluent reuse, local storage – most cost-effective
- Retain pws infrastructure for drought – conjunctive use?
- Joined up approach needed across all sectors – regional planning – all abstractions impact all water features



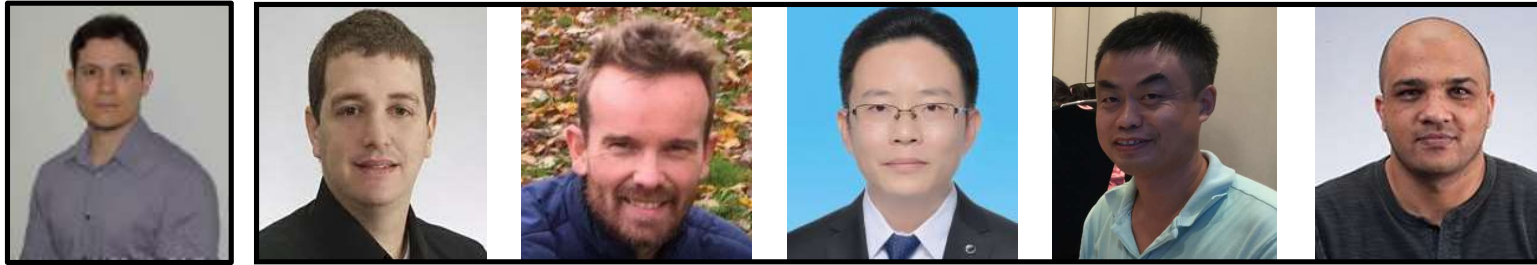


Conjunctive Management of Surface Water and Groundwater to Increase the Sustainability of Global Water Resources

Bridget R. Scanlon

Bureau of Economic Geology, Jackson School of Geosciences,
University of Texas at Austin





Post-docs
and visitors

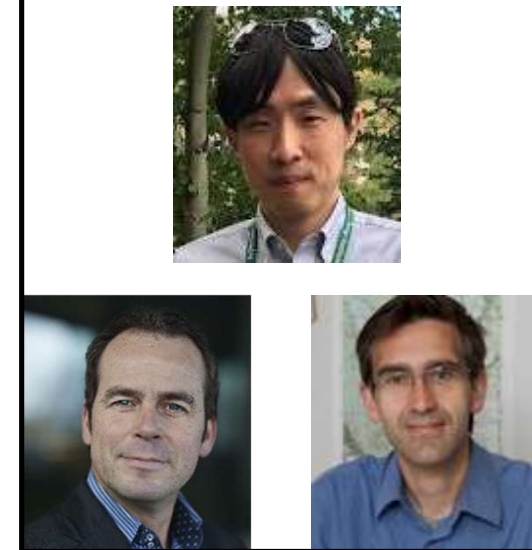
Global modelers

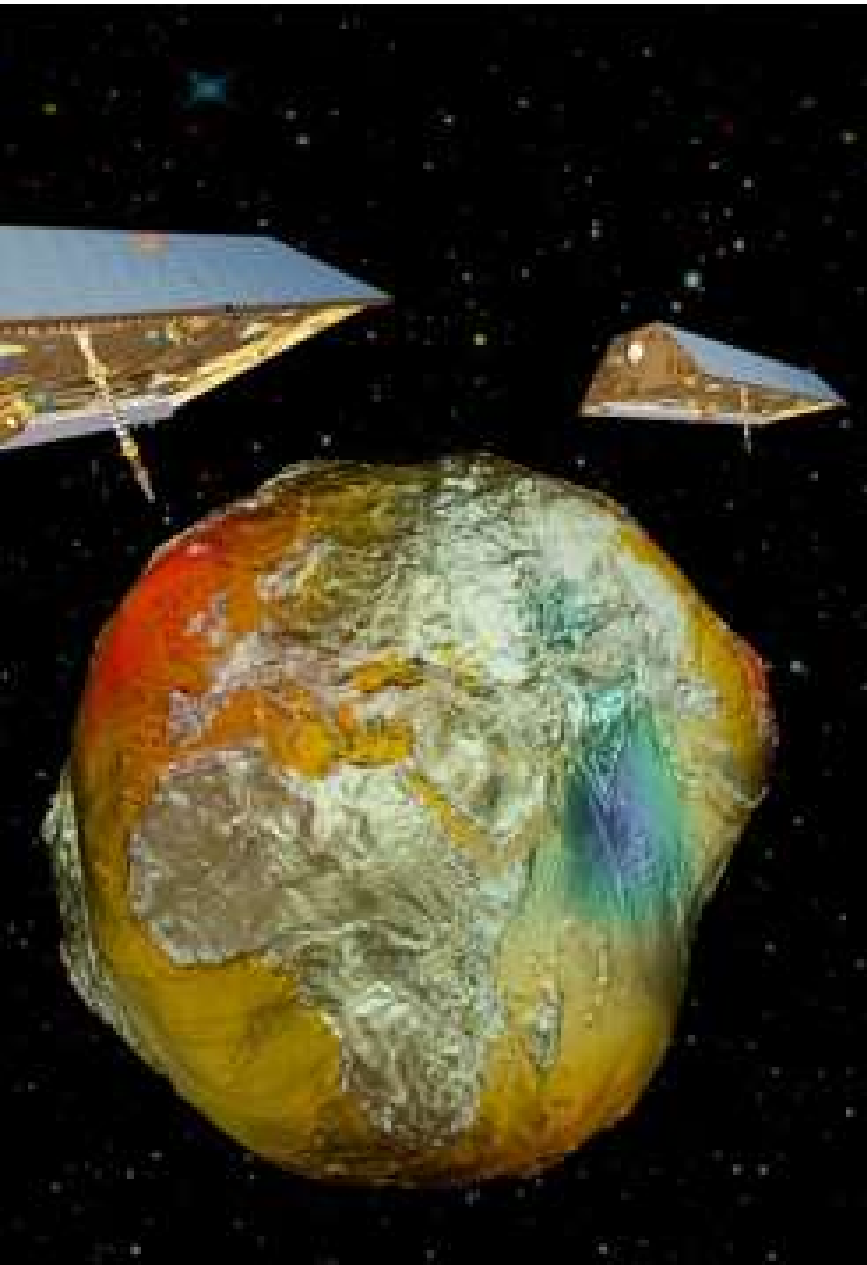


Geodesists



Hydrologists





Outline

1. Background
2. Global water resources using GRACE
3. Irrigation
 - a. Increase irrigation in Sub-Saharan Africa
 - b. Switching from SW to GW irrigation (NW India, Pakistan, NW US)
 - c. Conjunctive use of SW and GW (CA Central Valley)
 - d. Managed Aquifer Recharge: AZ + CA
4. Urban water shortages (Cape Town, Sao Paulo)

Groundwater: The hidden wealth of nations

GROUNDWATER IS NATURE'S INSURANCE



PROTECTS
FOOD SECURITY



REDUCES
POVERTY



BOOSTS
RESILIENT GROWTH

GROUNDWATER PROVIDES

49%

of all water withdrawn for
domestic use globally



43%

of irrigation water



Groundwater: The hidden wealth of nations

GROUNDWATER IS NATURE'S INSURANCE



PROTECTS
FOOD SECURITY



REDUCES
POVERTY



BOOSTS
RESILIENT GROWTH

GROUNDWATER PROVIDES

49%

of all water withdrawn for
domestic use globally



43%

of irrigation water

GW MITIGATES half of losses in
agricultural yield caused by drought



WITHOUT GROUNDWATER ACCESS,
droughts and the deprivations they cause can
increase the chances of stunting among children
under five by up to 20% in Sub-Saharan Africa



EASILY ACCESSIBLE AQUIFERS buffer
economic growth losses by 1/3rd drought



BUT

GW has been
undervalued,
overexploited in
Some regions
underexploited
in others



Up to 92% of TBAs in
ME & S Asia –GW
depletion. S Asia GW ag
revenue ↑10 – 20%

is declining as the resource depletes.



GW underused in SSA
> 225 M people:
poverty could be ↓ed
by ↑ *ing* shallow GW.



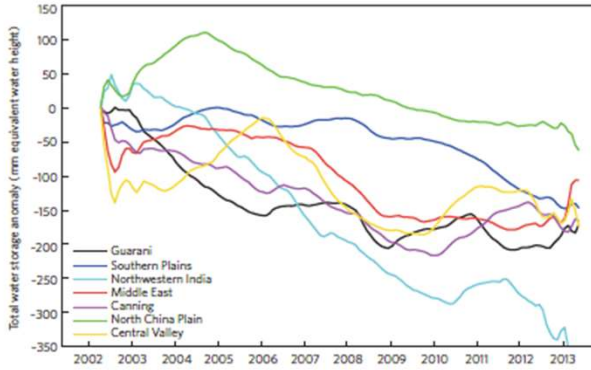
GROUNDWATER CAN PLAY A CRITICAL ROLE IN ADAPTING TO
CLIMATE CHANGE, BUT ONLY IF ACTION IS TAKEN TO PROTECT IT

COMMENTARY:

The global groundwater crisis

J. S. Famiglietti

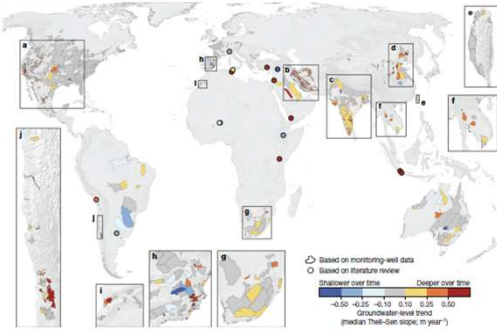
Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged.



Rapid groundwater decline and some cases of recovery in aquifers globally

<https://doi.org/10.1038/s41586-023-06879-8>
Received: 8 April 2023

Scott Jasechko^{1,2,3}, Hansjörg Seybold^{2,3}, Debra Perrone^{2,3}, Ying Fan⁴,
Mohammad Shamsudduha⁵, Richard G. Taylor⁶, Othman Fallatah^{7,8} & James W. Kirchner^{2,9,10}



nature sustainability

Article

<https://doi.org/10.1038/s41893-024-01306-w>

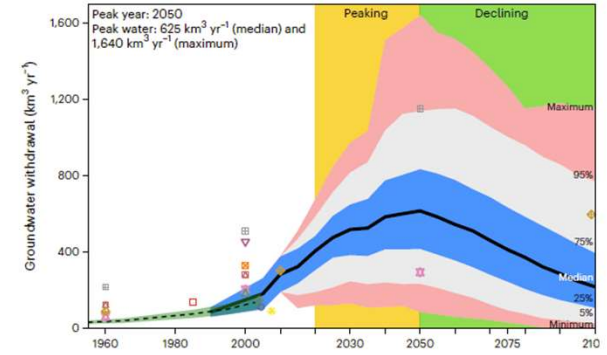
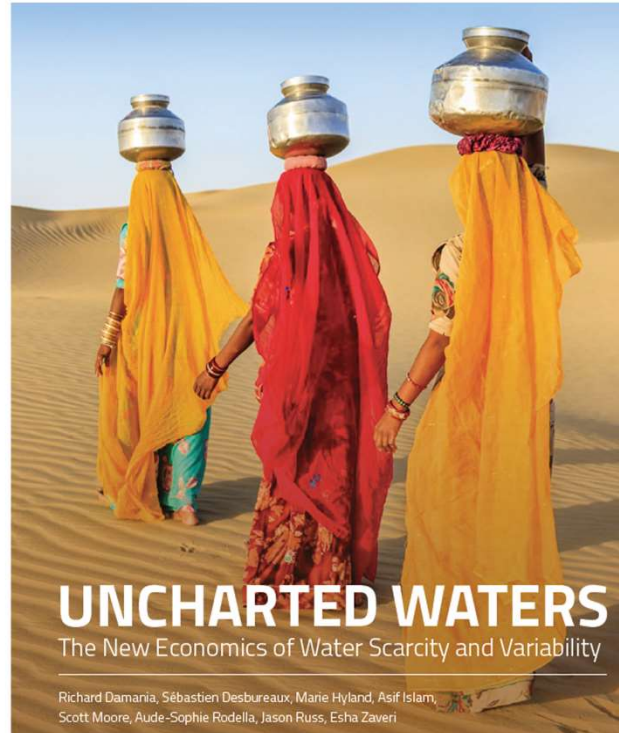
Global peak water limit of future groundwater withdrawals

Received: 24 May 2023

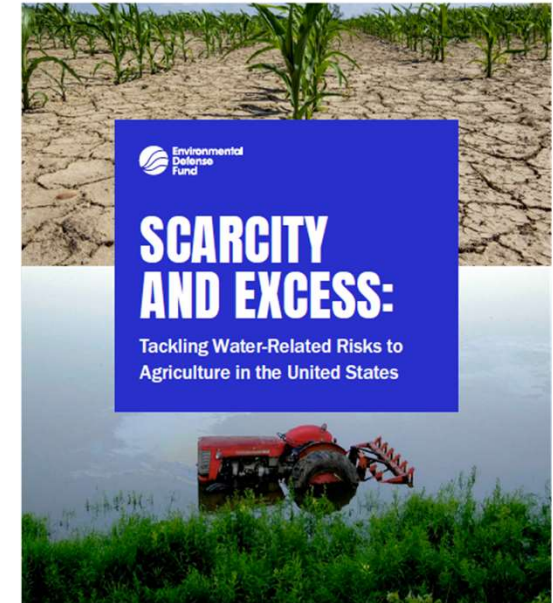
Accepted: 6 February 2024

Published online: 22 April 2024

Hassan Niazi¹, Thomas B. Wild², Sean W. D. Turner³, Neal T. Graham⁴,
Mohamad Hejazli⁵, Stwa Msangi⁶, Son Kim⁷, Jonathan R. Lamontagne⁸
& Mengqi Zhao⁹



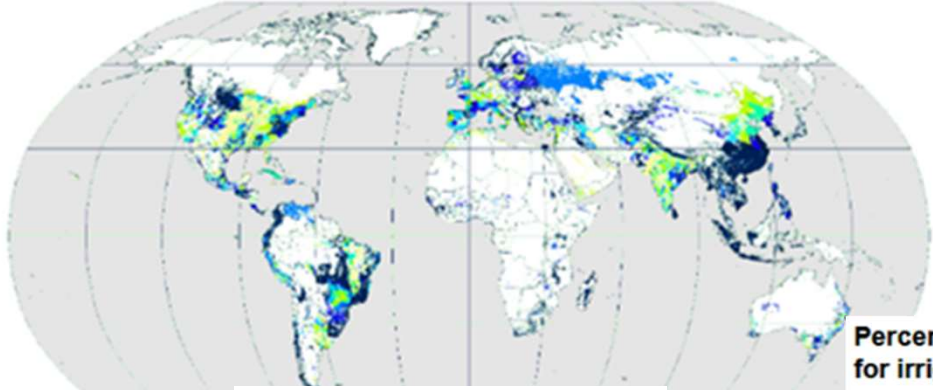
Too much vs too little?



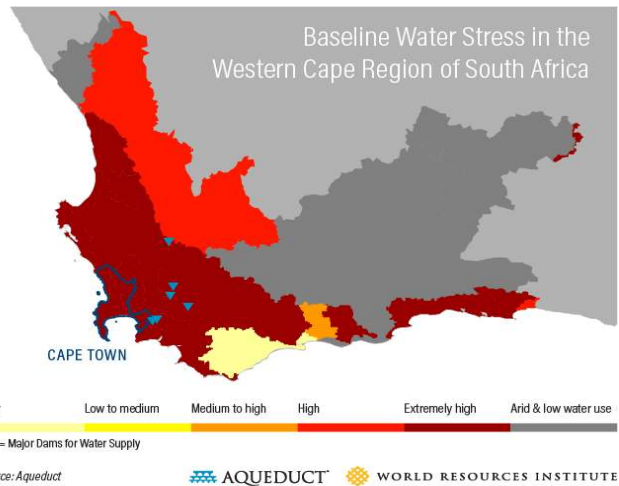
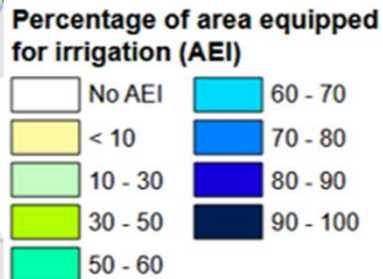
1. Irrigation, Food Production, and Urban Water

Cape Town Day Zero

Surface Water Irrigation



Groundwater Irrigation



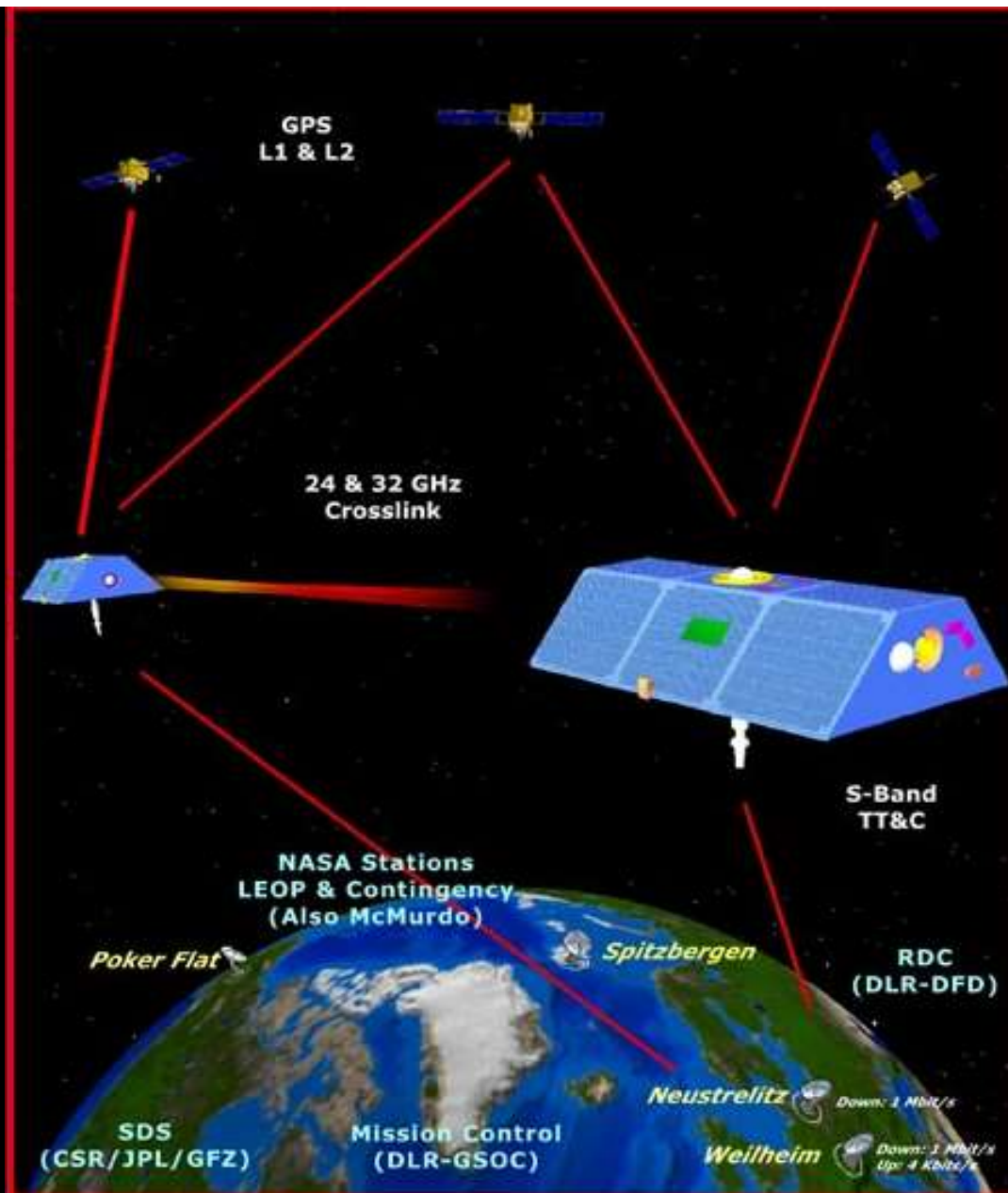
Sao Paulo



Irrigation: 70% of global water withdrawal
90% of global water consumption

<http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm>

Siebert et al., HESS, 2010



2. GRACE

Gravity Recovery and Climate Experiment

GRACE: March 2002 – 2017 (low solar activity)
 GRACE Follow-On: 2018 →

500 km above land surface controls resolution of GRACE data
 Resolution: ~350 km, ~120,000 km²

Satellites 220 km apart

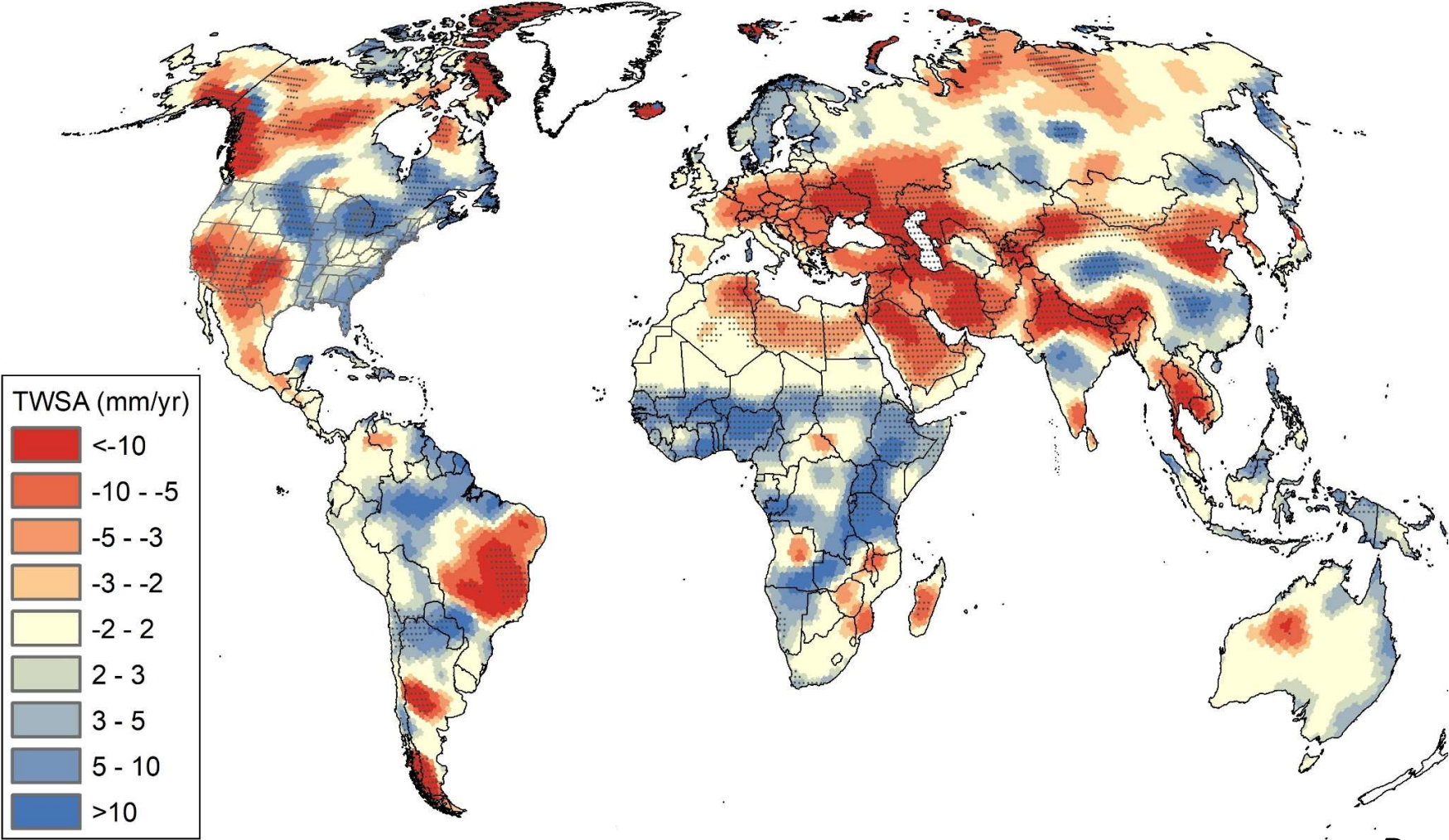
Monthly data
 1 gigaton mass change = 1 km³ of water

Terrestrial water storage (TWS) change

Essential climate variable in
 Global Climate Observing System

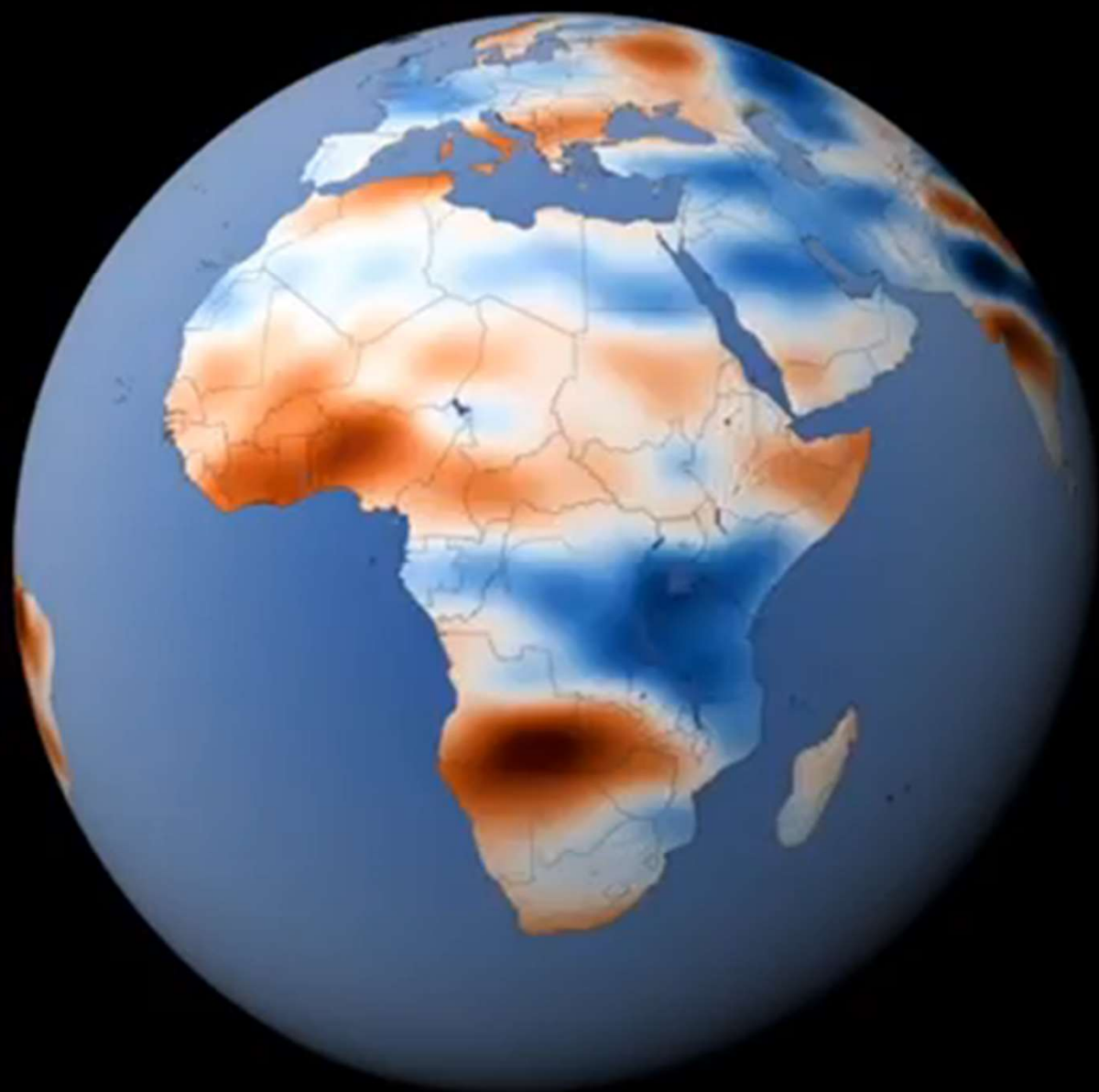
<http://grace.jpl.nasa.gov/mission/gravity-101/>

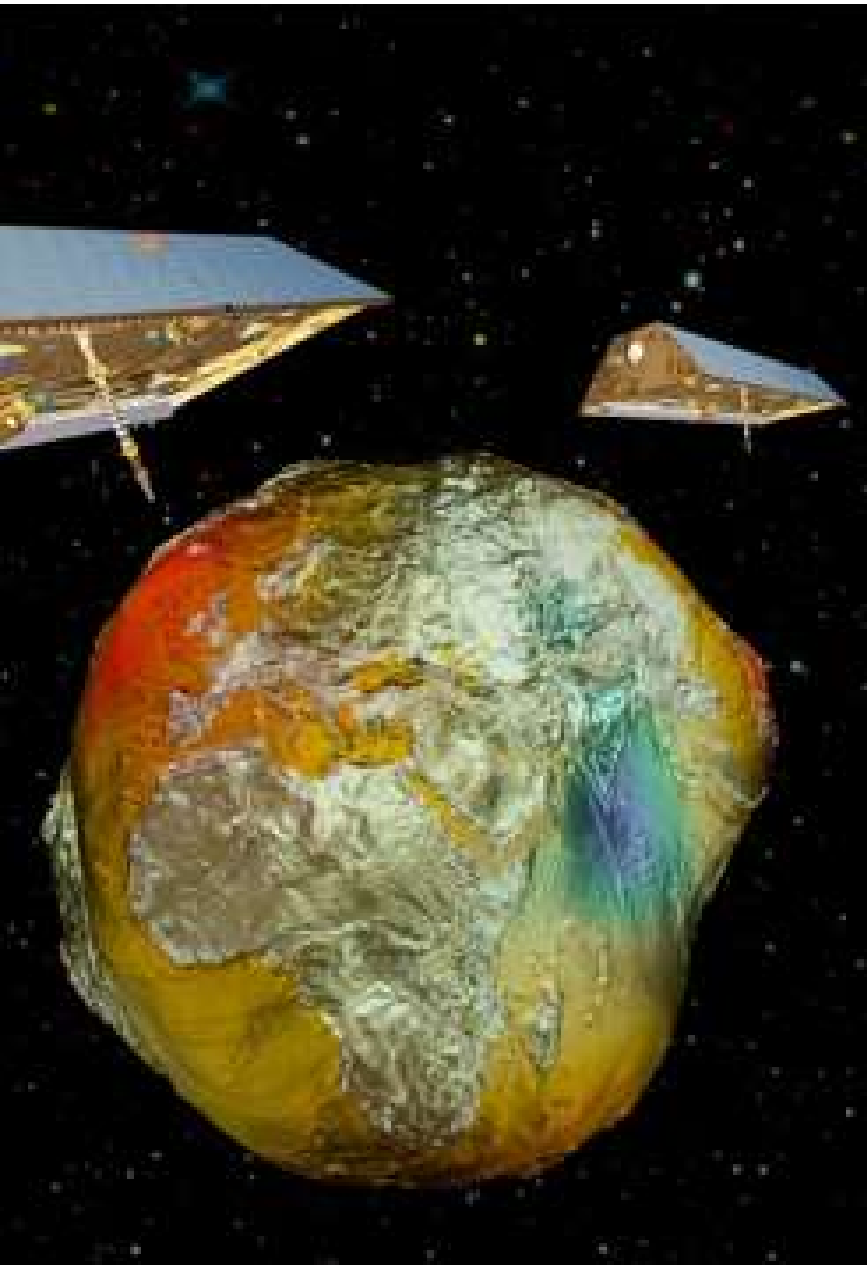
2. GRACE Total Water Storage Anomalies (04/2002 – 09/2021)



Rateb et al., 2022

Jun 21, 2002



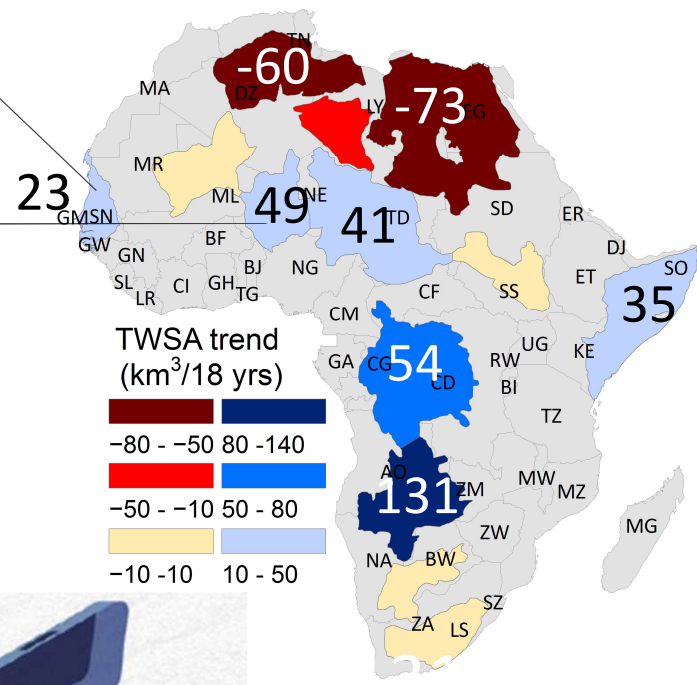
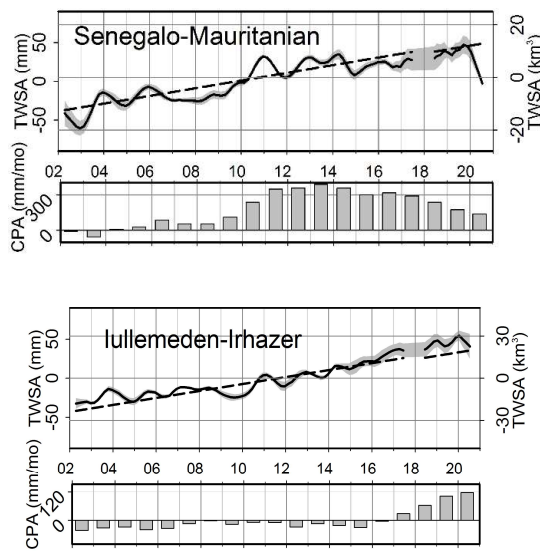


Outline

1. Background
2. Global water resources using GRACE
3. Irrigation
 - a. Increase irrigation in Sub-Saharan Africa
 - b. Switching from SW to GW irrigation (NW India, Pakistan, NW US)
 - c. Conjunctive use of SW and GW (CA Central Valley)
 - d. Managed Aquifer Recharge: Arizona
4. Urban water shortages (Cape Town, Sao Paulo)

3a. Potential to Expand Irrigation in Sub-Saharan Africa

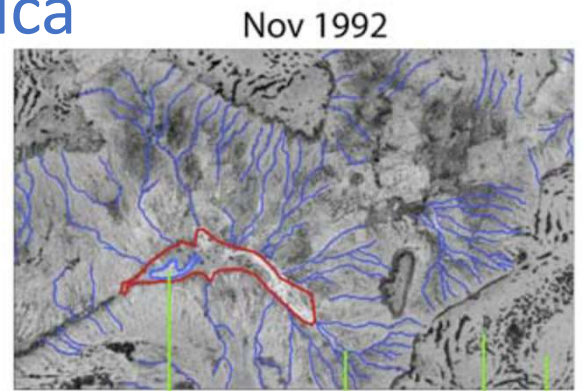
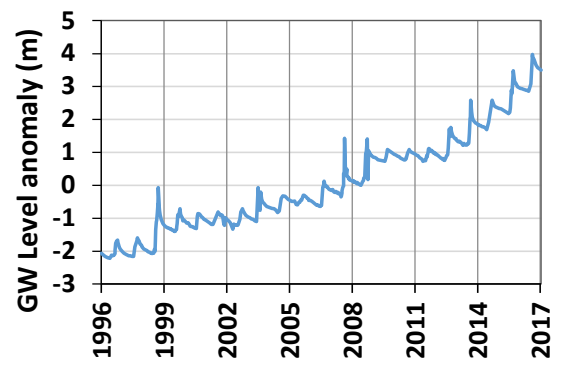
GRACE Total Water Storage Anomaly (2002 – 2020)



40% basement aquifers
Self-regulating

Favreau et al., WRR, 2009
Scanlon et al., ERL, 2022

GW level hydrograph Niger

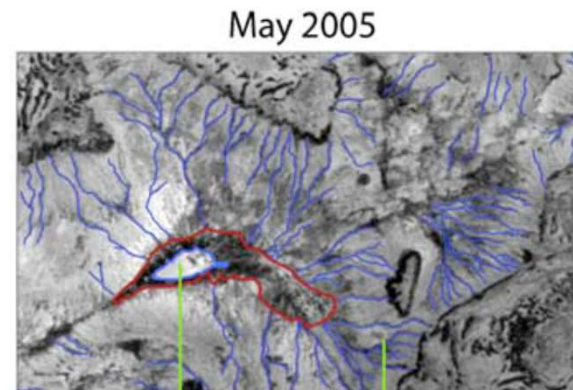


new pond in red: shoreline
in blue: water

sparse tiger bush

connected, high density drainage network

wide, open bare soil area

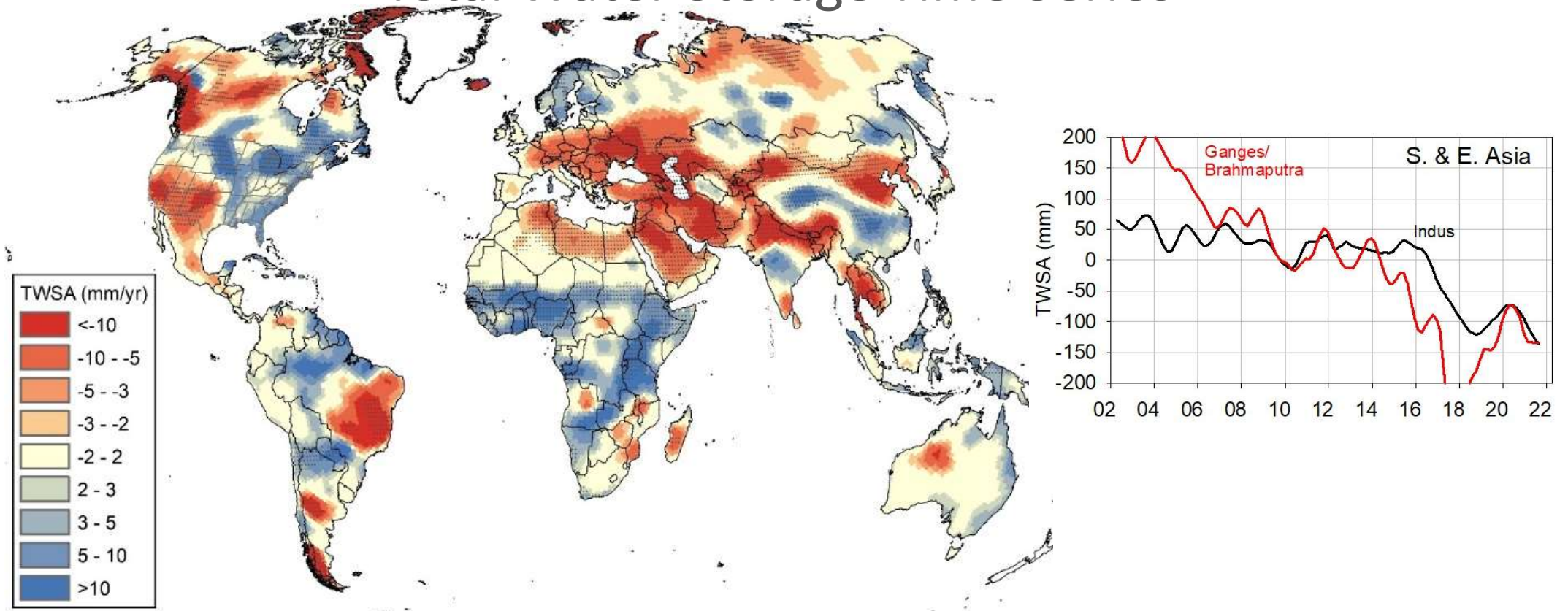


expanded pond in red: shoreline
in blue: water

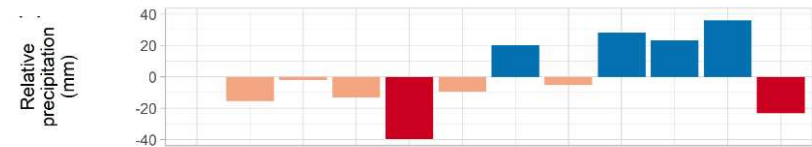
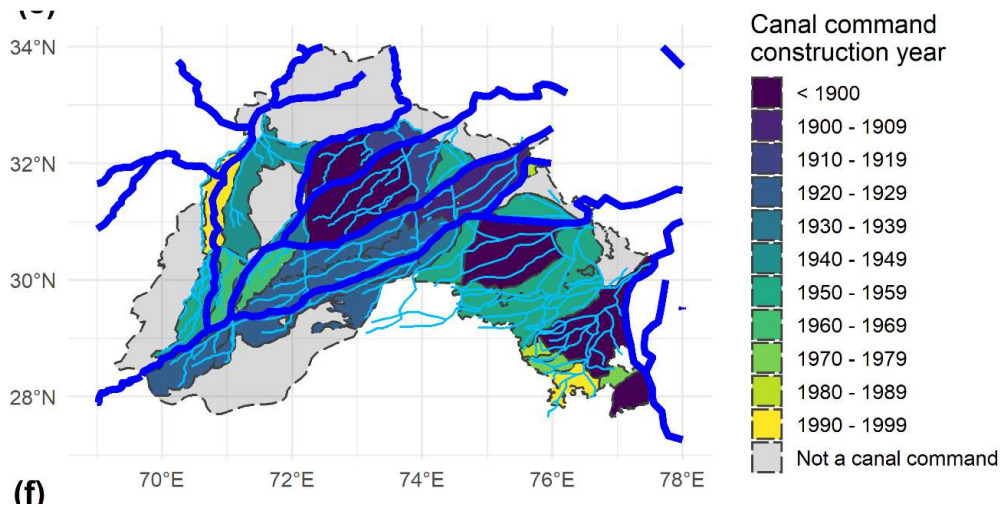
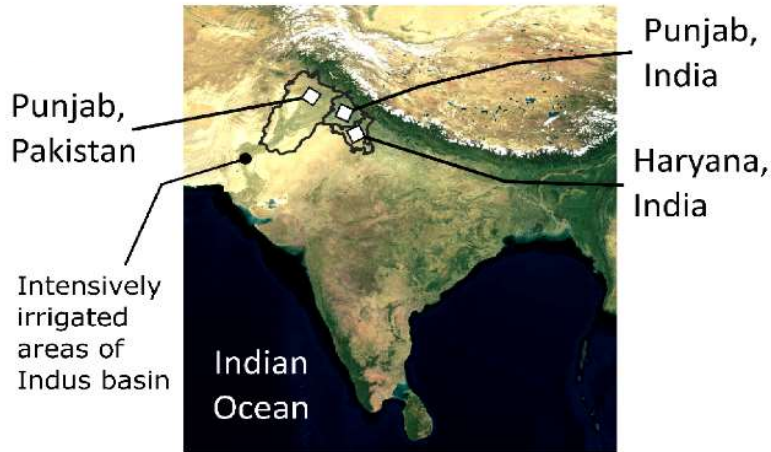
connected, high density drainage network;

3b. Switching from Surface Water to Groundwater Irrigation

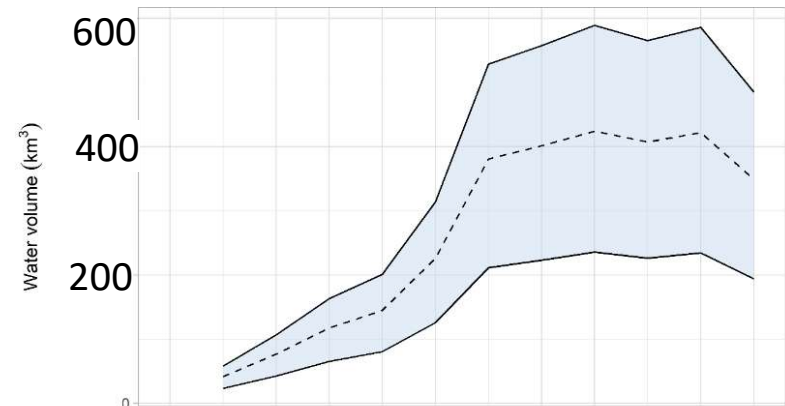
Total Water Storage Time Series



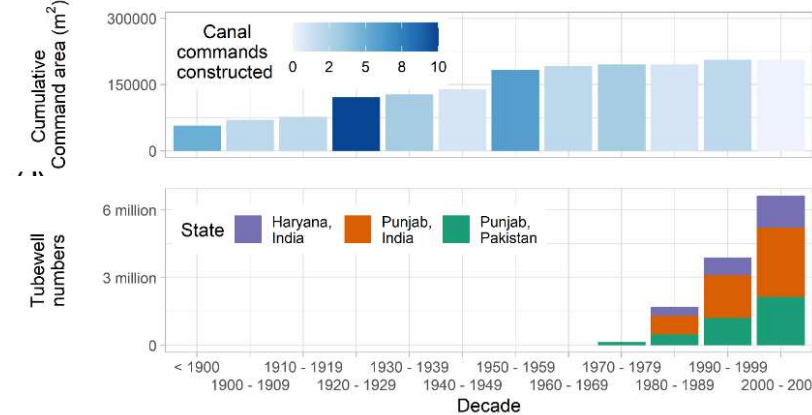
3b. A century of groundwater accumulation in Pakistan and Northwest India (GW level monitoring)



Precip. Anomaly



Water Storage km³



Canals

Tubewells

3b. Indo-Gangetic Basin

North India running out of water, confirms NASA

CHANDIGARH: The worst fears about the northern region of the country losing its groundwater have been confirmed. The National Aeronautics and Space Administration's (NASA) satellite imagery made available to the Centre warns of fast disappearing of subsoil water in these states.

Updated At: Aug 16, 2015 02:04 PM (IST)



Follow Us

FOLLOW ON Google News India News

Twitter Facebook YouTube Instagram

Home / India News / Significant drop in volume of water in Ganga, flags WMO

Significant drop in volume of water in Ganga, flags WMO

ENVIRONMENT

Groundwater Withdrawals Across India Have Increased Tenfold in Six Decades

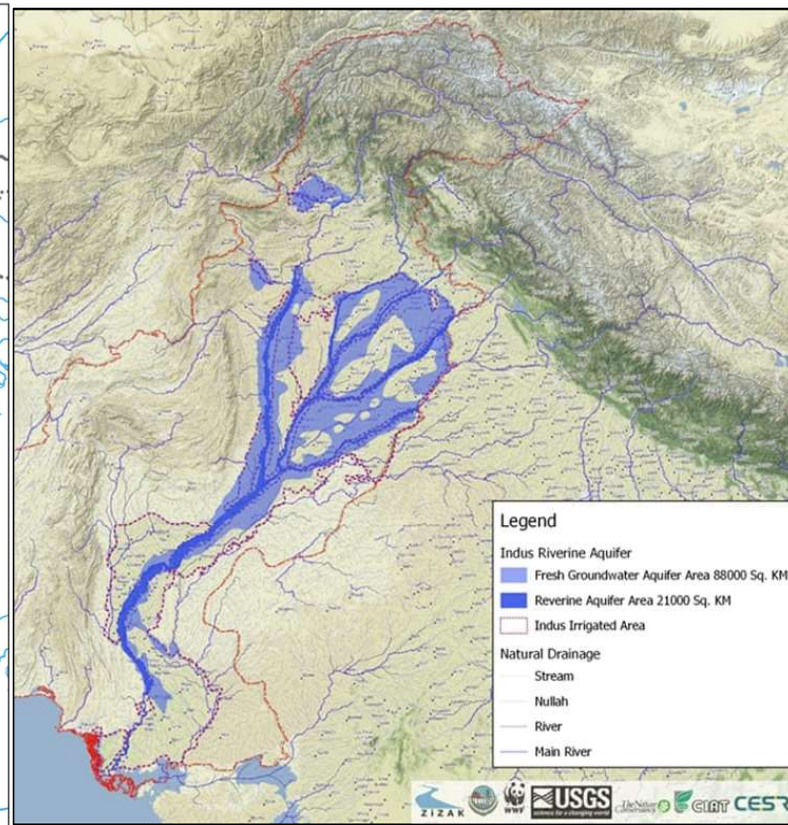
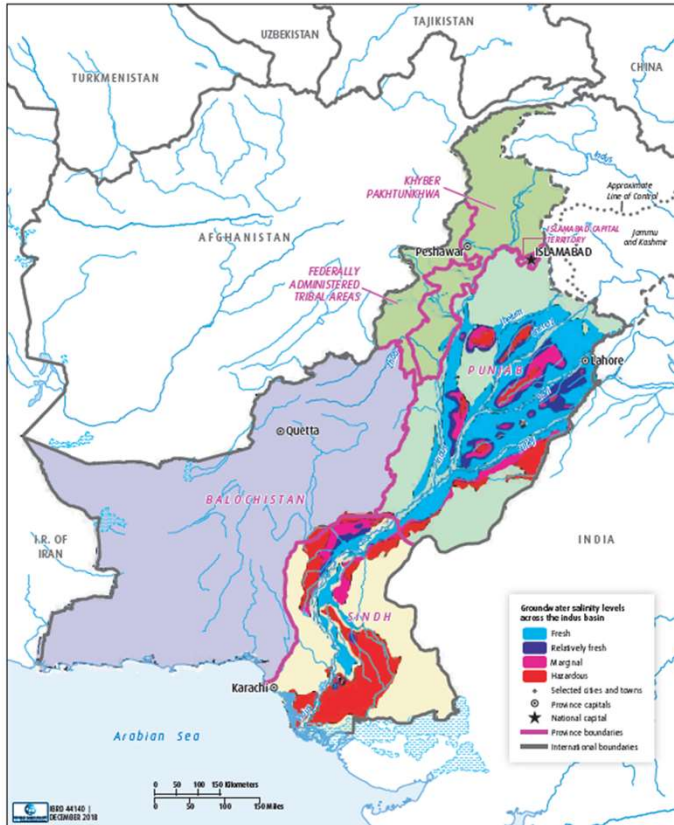
In many rainfall-scarce areas, groundwater has been exploited to plant water-guzzling crops like paddy and sugarcane, especially in Vidarbha and Rayalaseema.



Government response with aid from **World Bank**:
National program: Atal Bhujal Yojana, 7 states switching from GW wells to irrigation canals
Punjab: Save Water, Earn Money scheme
 Incentivizes farmers to reduce groundwater use
 Some **cities** in Punjab moving from GW to canals

<https://www.worldbank.org>

3b. Switching from Surface-Water to Groundwater Irrigation in Indus Basin



SW irrigation, 1900s
 Water logging and
 GW salinization
 Qureshi et al., 2004

Freshwater aquifers, Indus Plains and
 riverine corridors, ~ 500 km³
 Hussain and Abbas, DE, 2019

Solutions:

- Salinity Control and Reclamation Project (**SCARP**): 1.5 million tube wells installed waterlogged areas
- Conjunctive use** of SW and GW
- GW depletion**: water level declines ≤ 1 m/yr in some areas.
- Recharge Pakistan** project: GW recharge wells, nature based solutions to recharge aquifer, wetland restoration

Groundwater and Surface water challenges in Indus Basin Irrigation System, Pakistan

Azeem Shah talks about water issues in Pakistan, including transboundary issues, solar irrigation, and improving data for more sustainable management of water resources.

WATER RESOURCES PODCAST
 with Bridget Scanlon

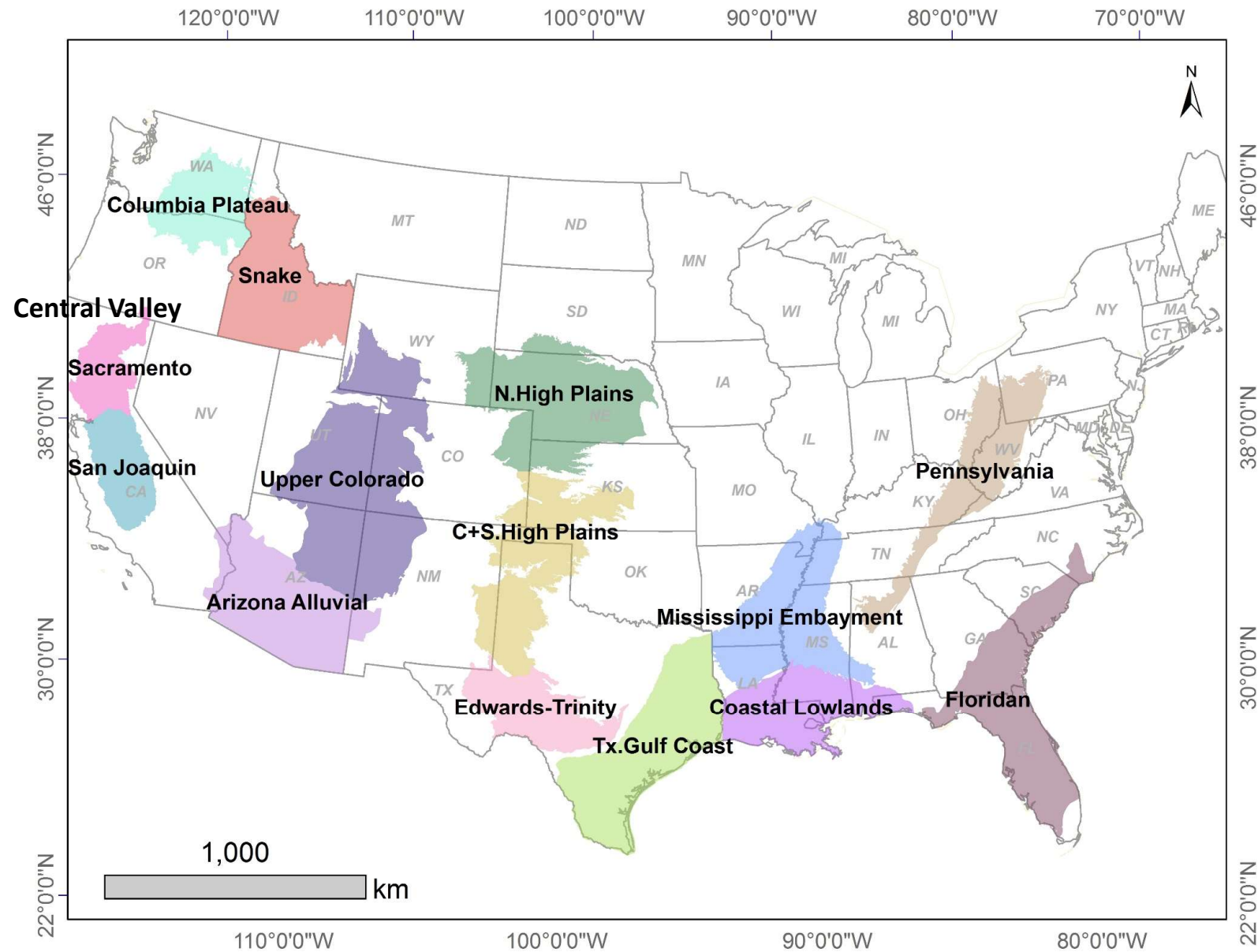
Azeem Shah, WRP, 2025

3b. Major Aquifers (14)

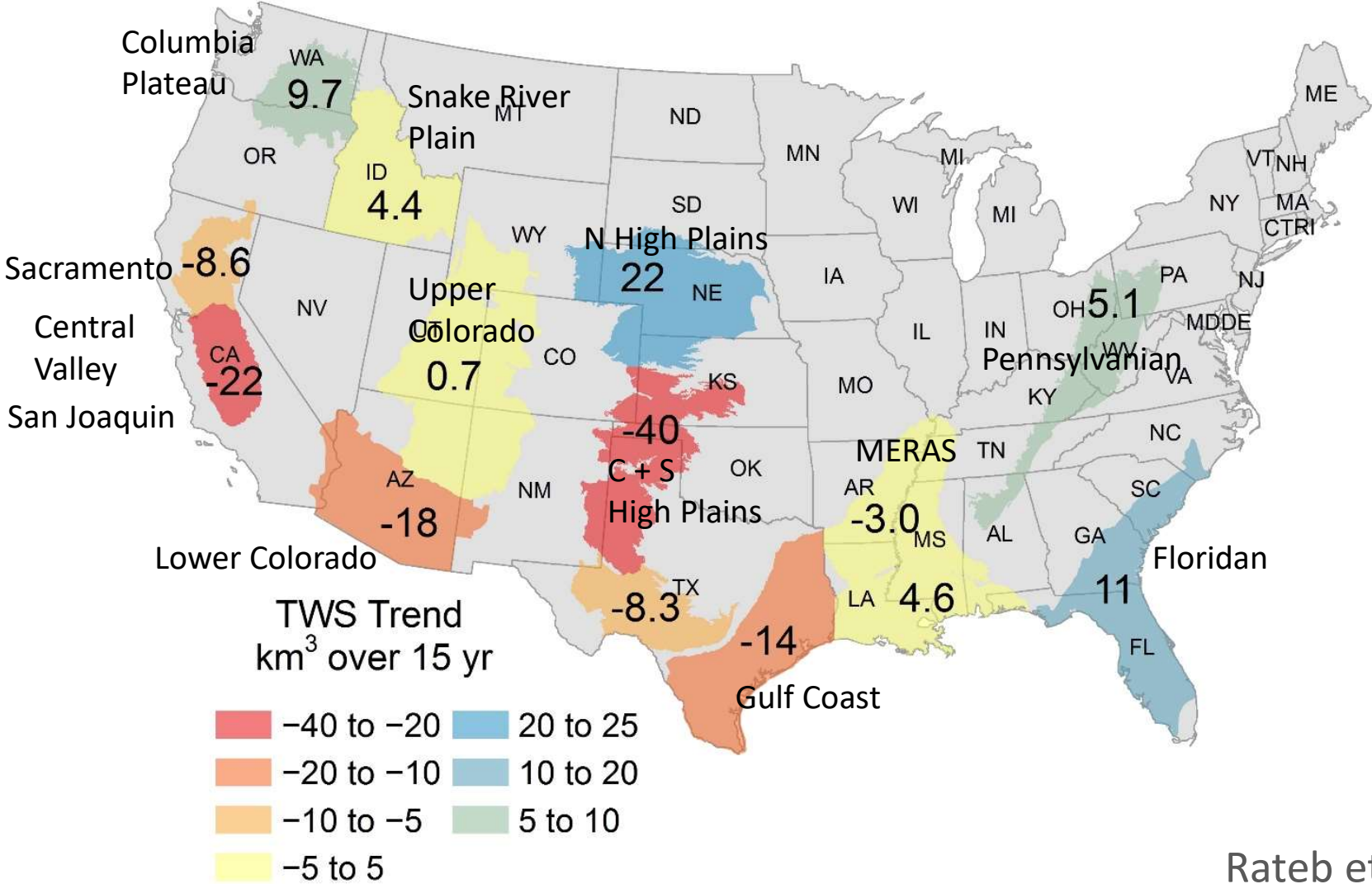
Unconfined aquifers
High Plains, AZ Alluvial, Upper Colorado, Snake

Semi-confined aquifers
Columbia & Central Valley:

Confined
All other aquifers

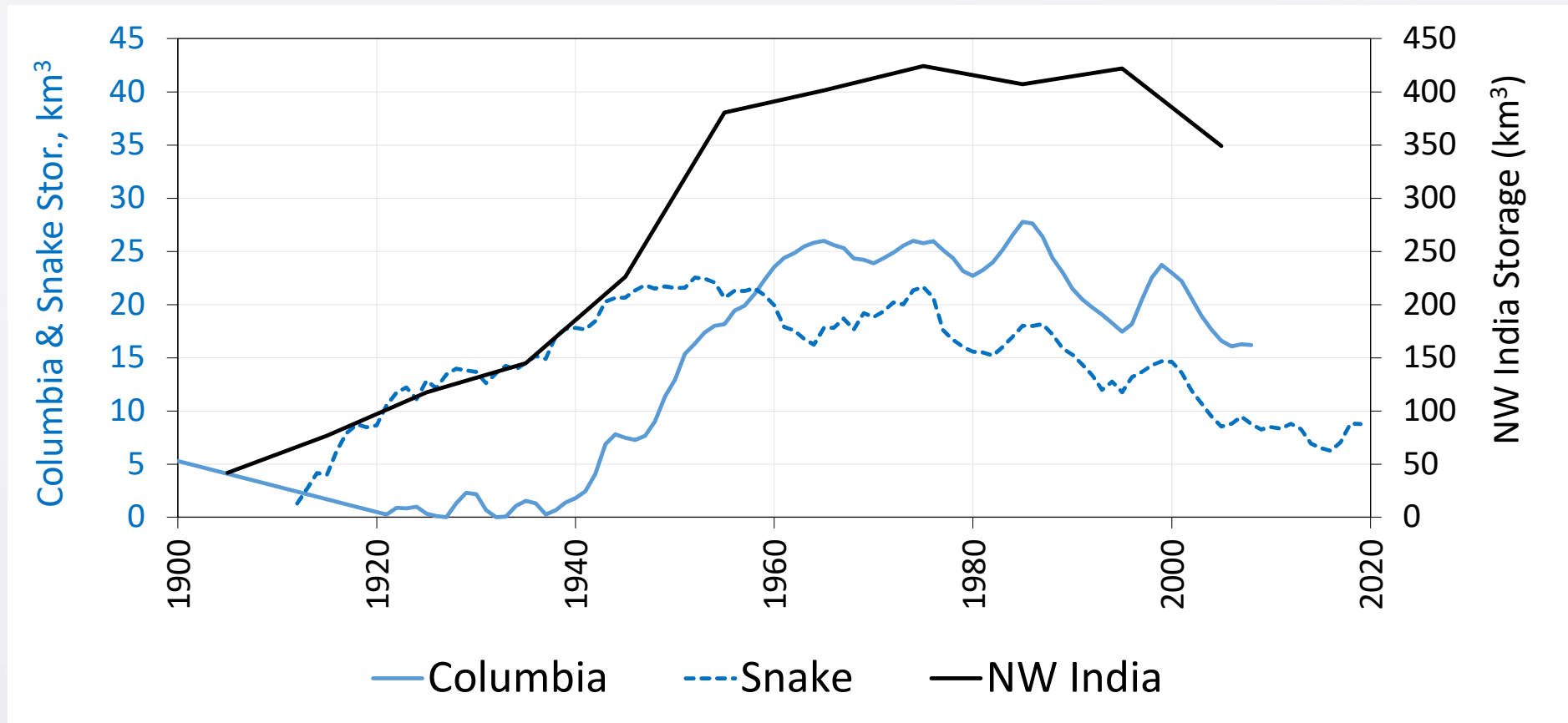


3b. Total Water Storage Trends in the U.S. (GRACE: 2002 – 2017)



Rateb et al., WRR, 2021

3b. Long-term Trends in Groundwater Storage

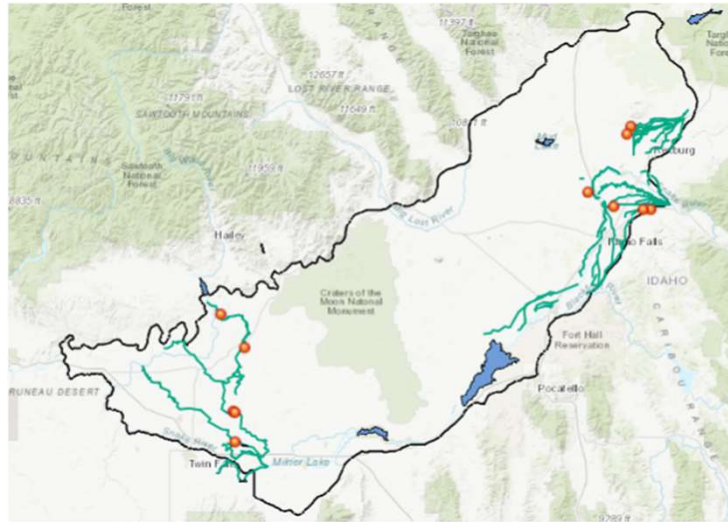


Increases in GW storage attributed to surface water irrigation
Columbia and Snake River Basins, NW US

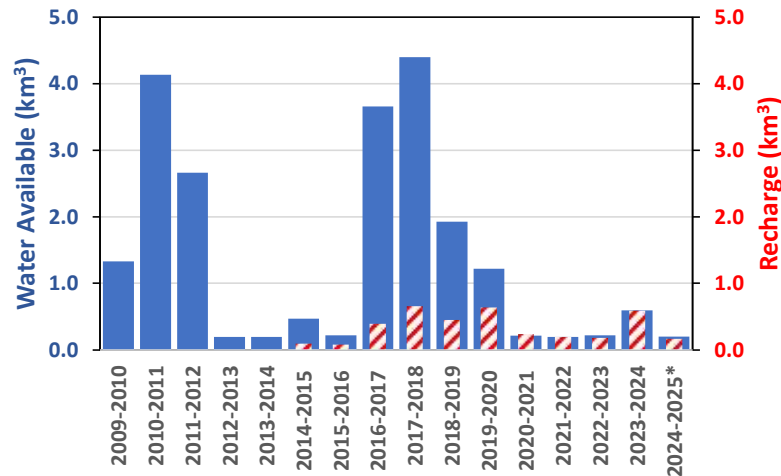
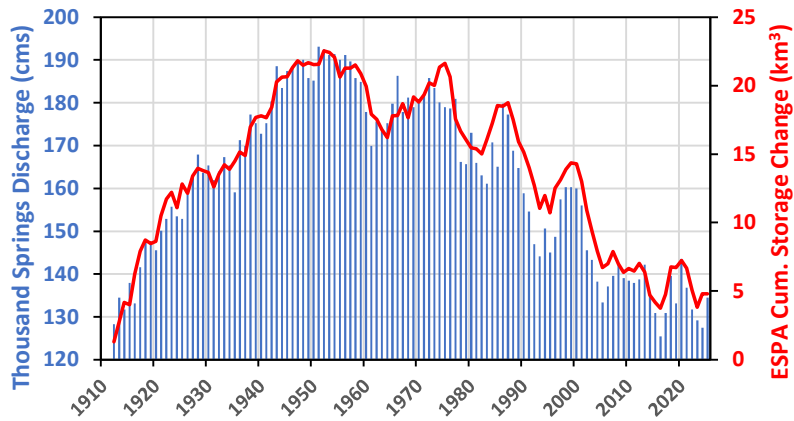
3b. Eastern Snake Plain Aquifer Recharge



Managed Aquifer Recharge Projects



Egin Lakes Recharge project

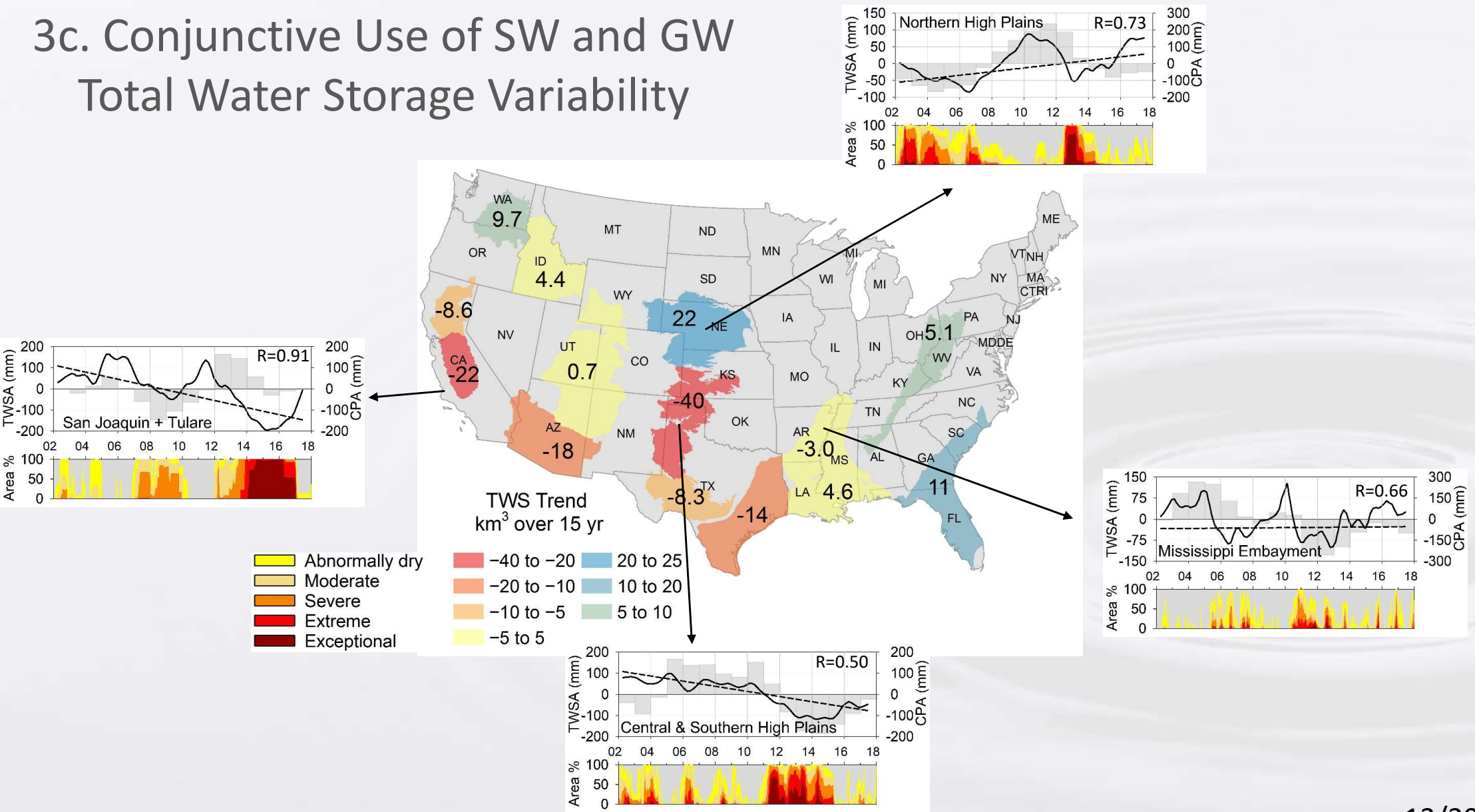


Irrigation infrastructure

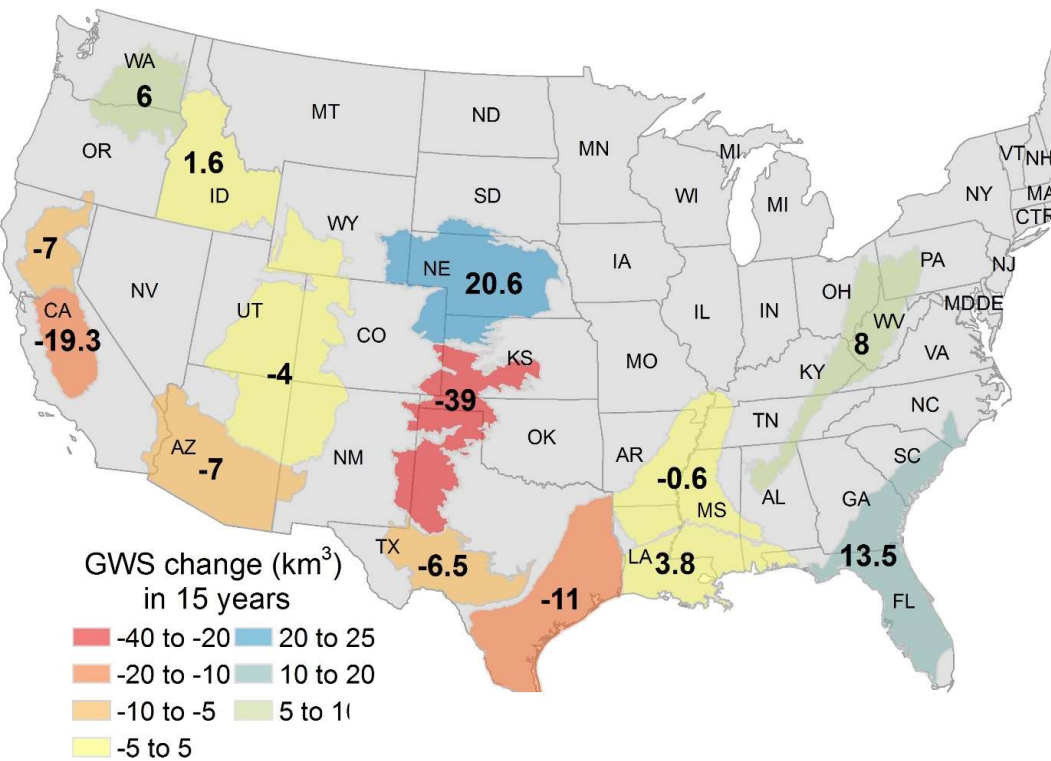
Hikpe et al., GW, 2022

<http://idwr.idaho.gov/water-data/projects/espam/>

3c. Conjunctive Use of SW and GW Total Water Storage Variability

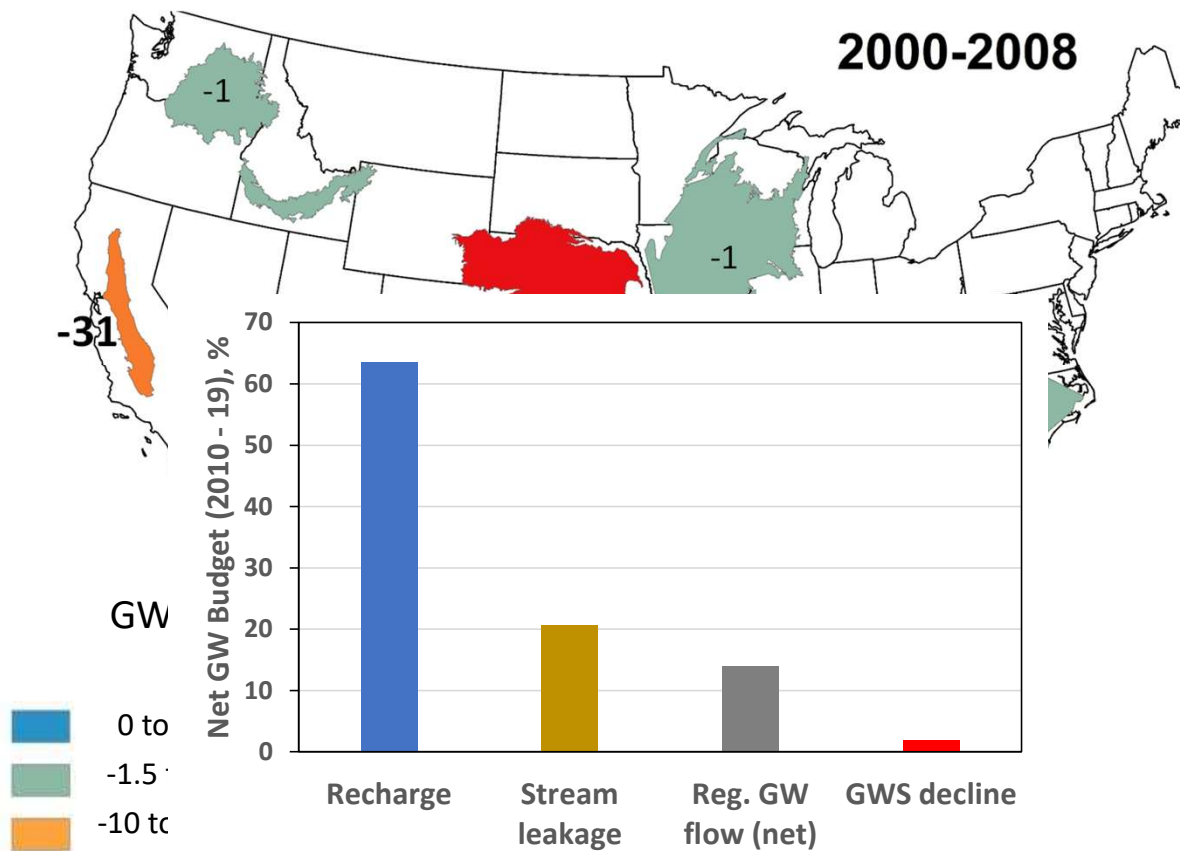


GW Storage Change GRACE (2002 – 2017)



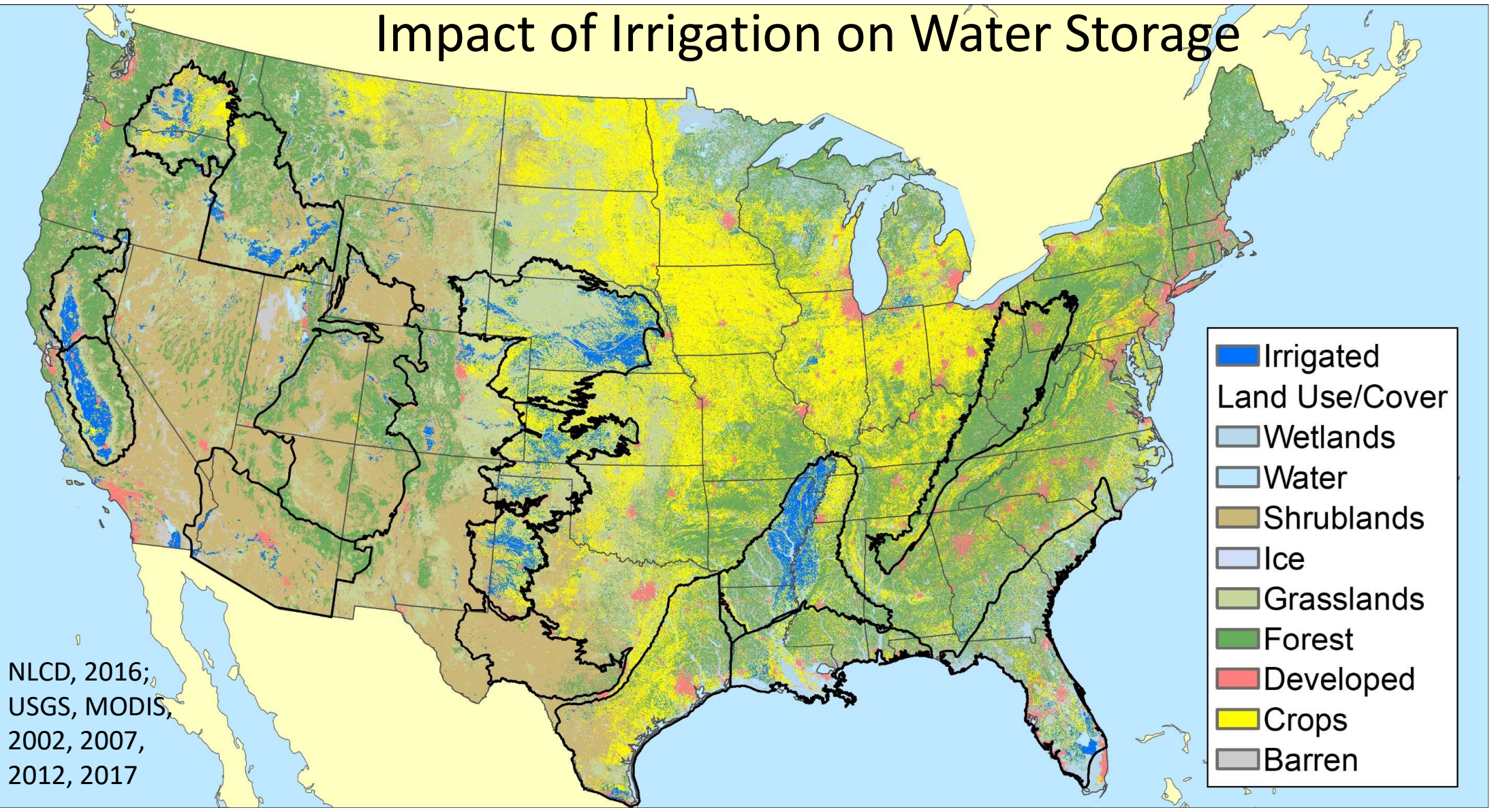
Rateb et al., 2020

GW Storage Change Regional Models and Monitoring 2000-2008



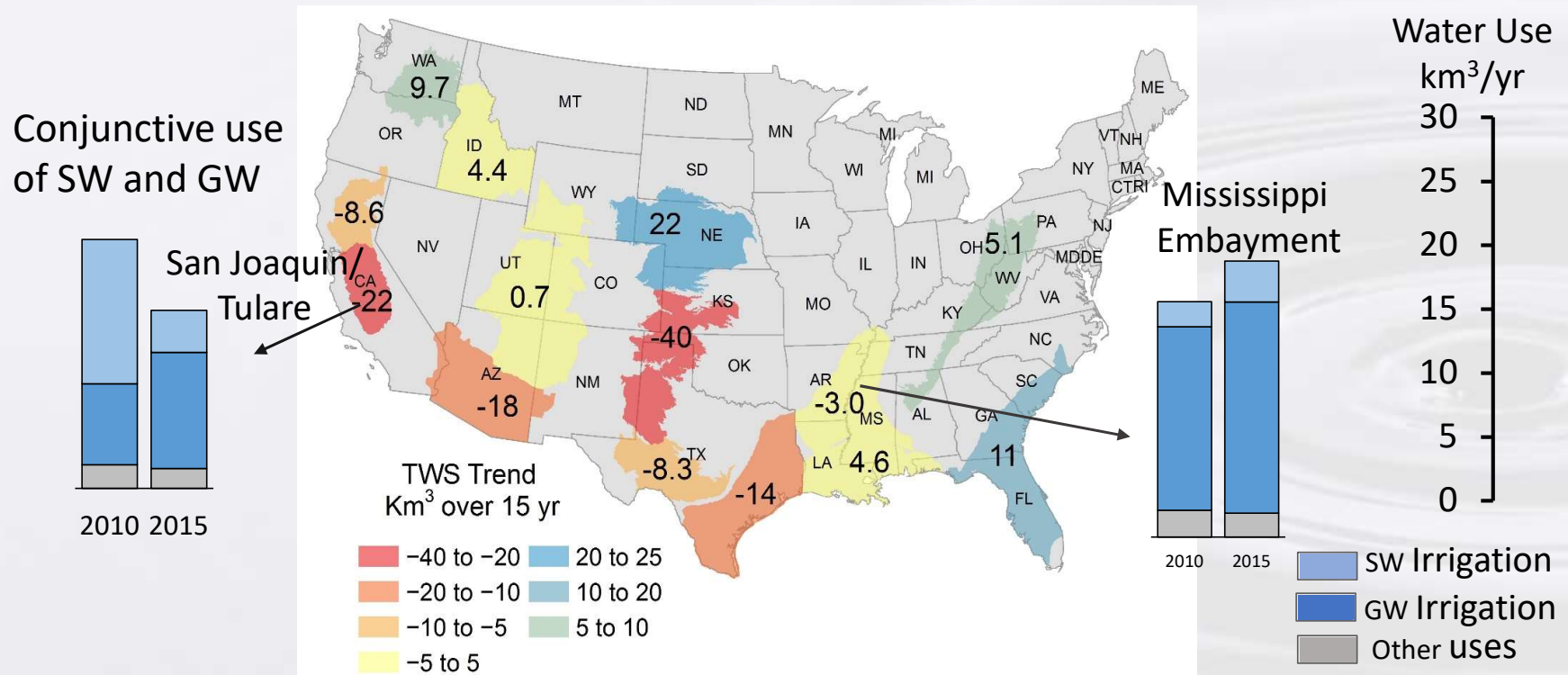
Konikow et al., 2011

Impact of Irrigation on Water Storage



NLCD, 2016;
USGS, MODIS,
2002, 2007,
2012, 2017

3c. Irrigation Water Use



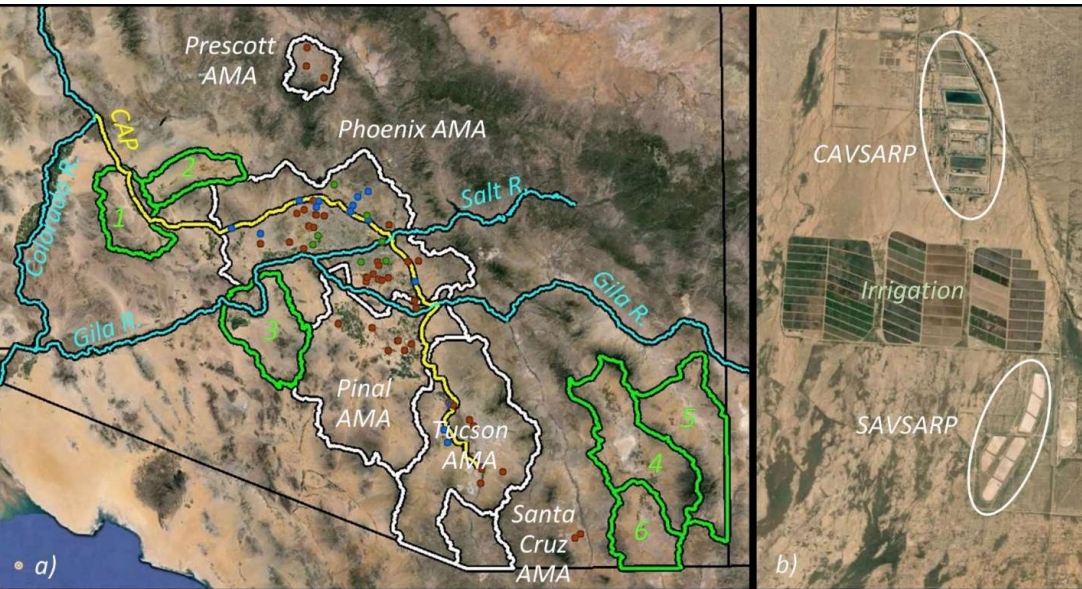
2010: wet year: 70% SW
 2015: drought: 70% GW

Scanlon et al., ERL, 2021

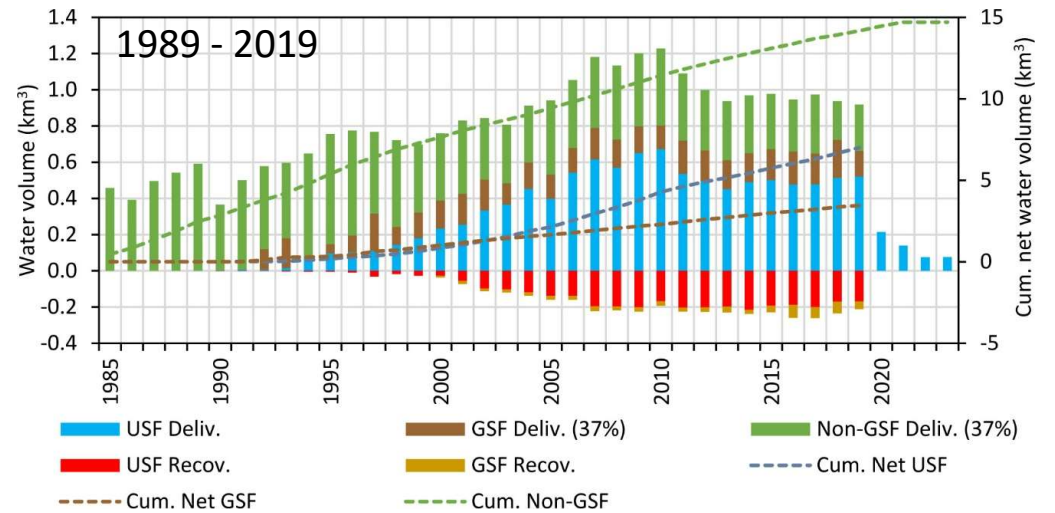
3d. Managed Aquifer Recharge: Arizona Alluvial Valley

Central AZ Project (CAP)
Active Manag. Areas (AMAs)

USF:
Spreading basins



Recharge in Active Management Areas



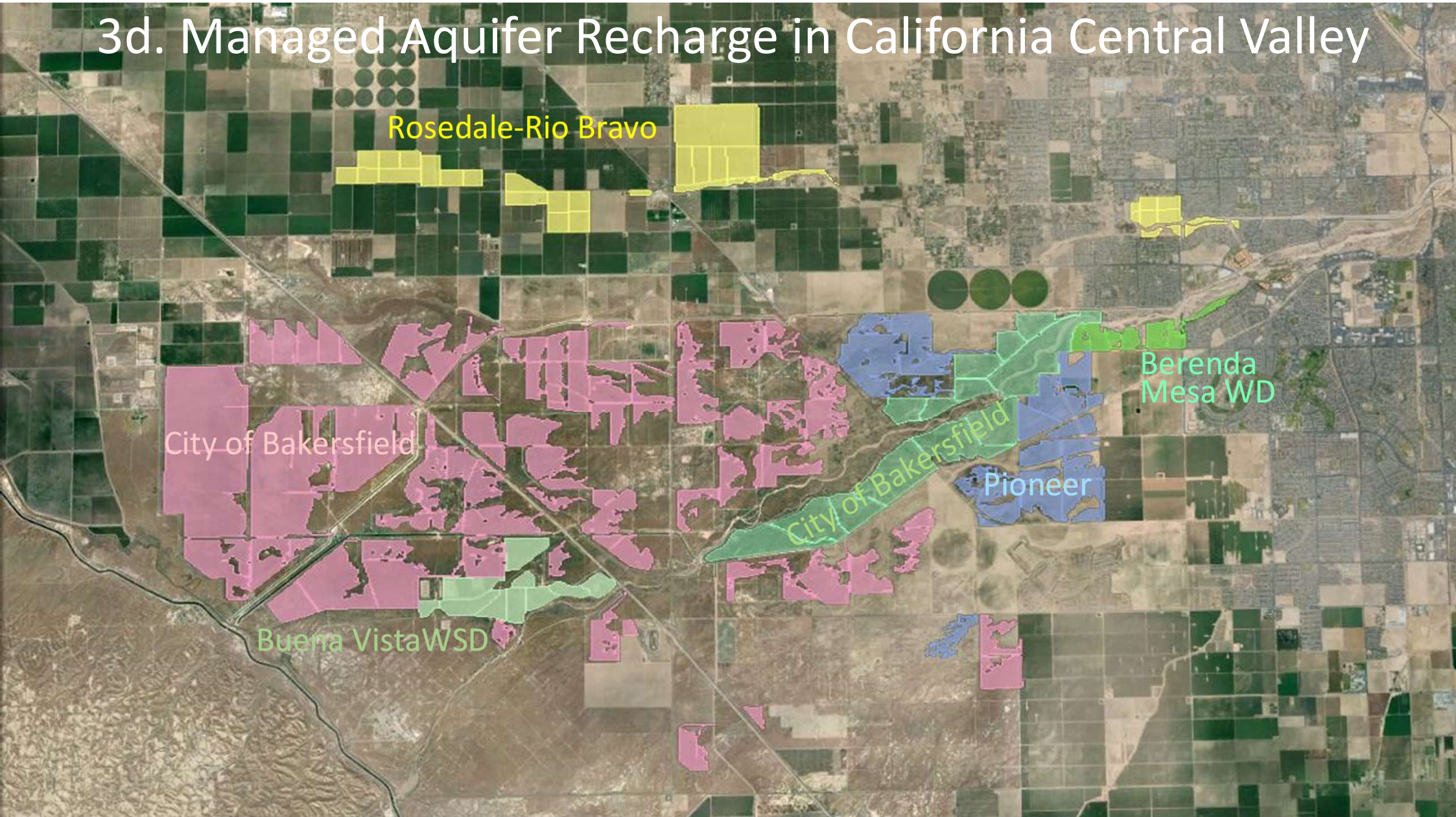
Arizona: **Pump and Replenish**

Pumping GW and replenishing it with MAR is 1000 × less expensive than developing SW treatment plant

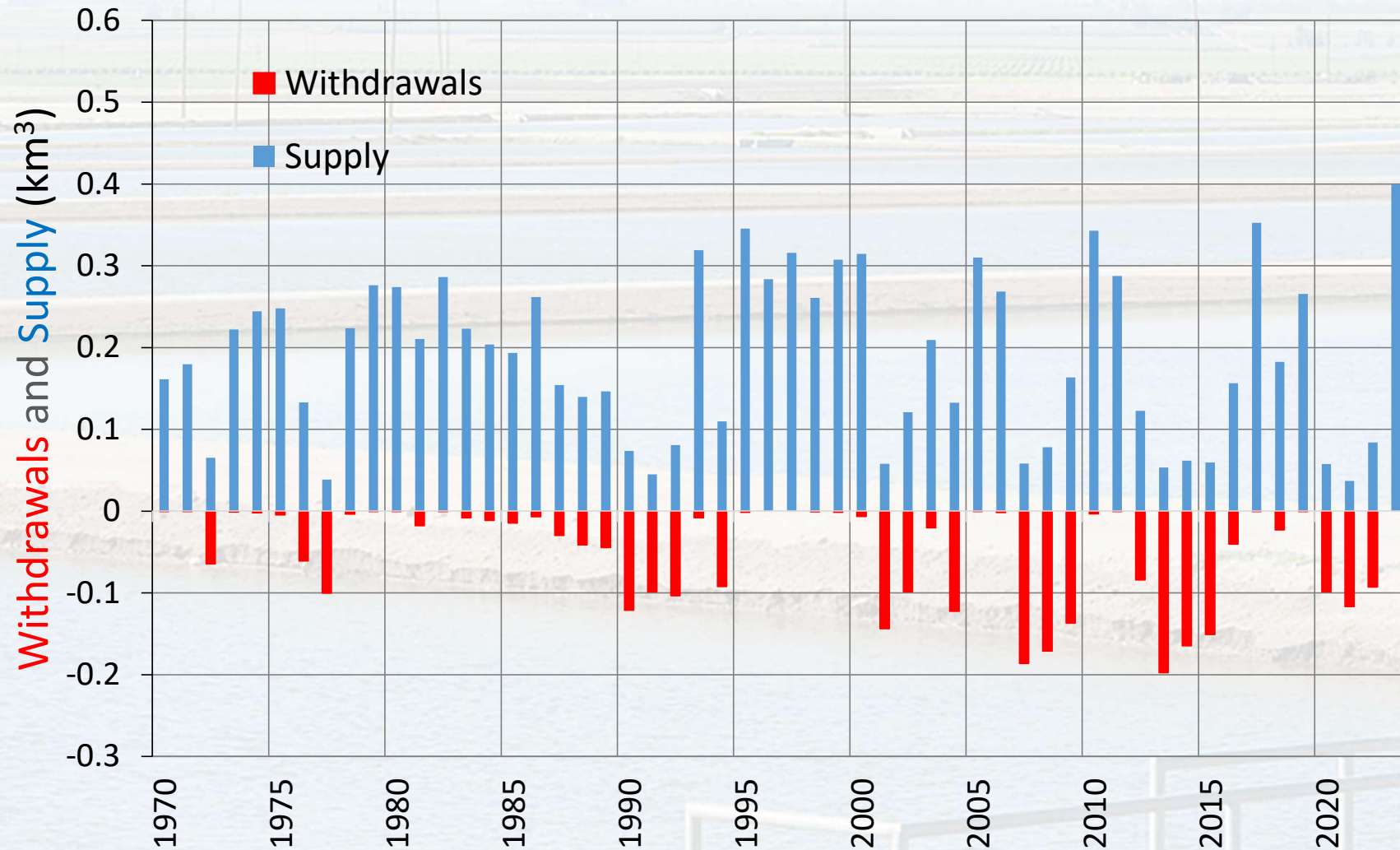
USF: **Underground Storage Facilities: 7.0 km³**
 GW Savings Facilities: **3.5 km³ (Switch GW → SW)**
 Incidental Recharge: **14.2 km³ (SW irrigation)**

Scanlon et al., NCEE, 2025

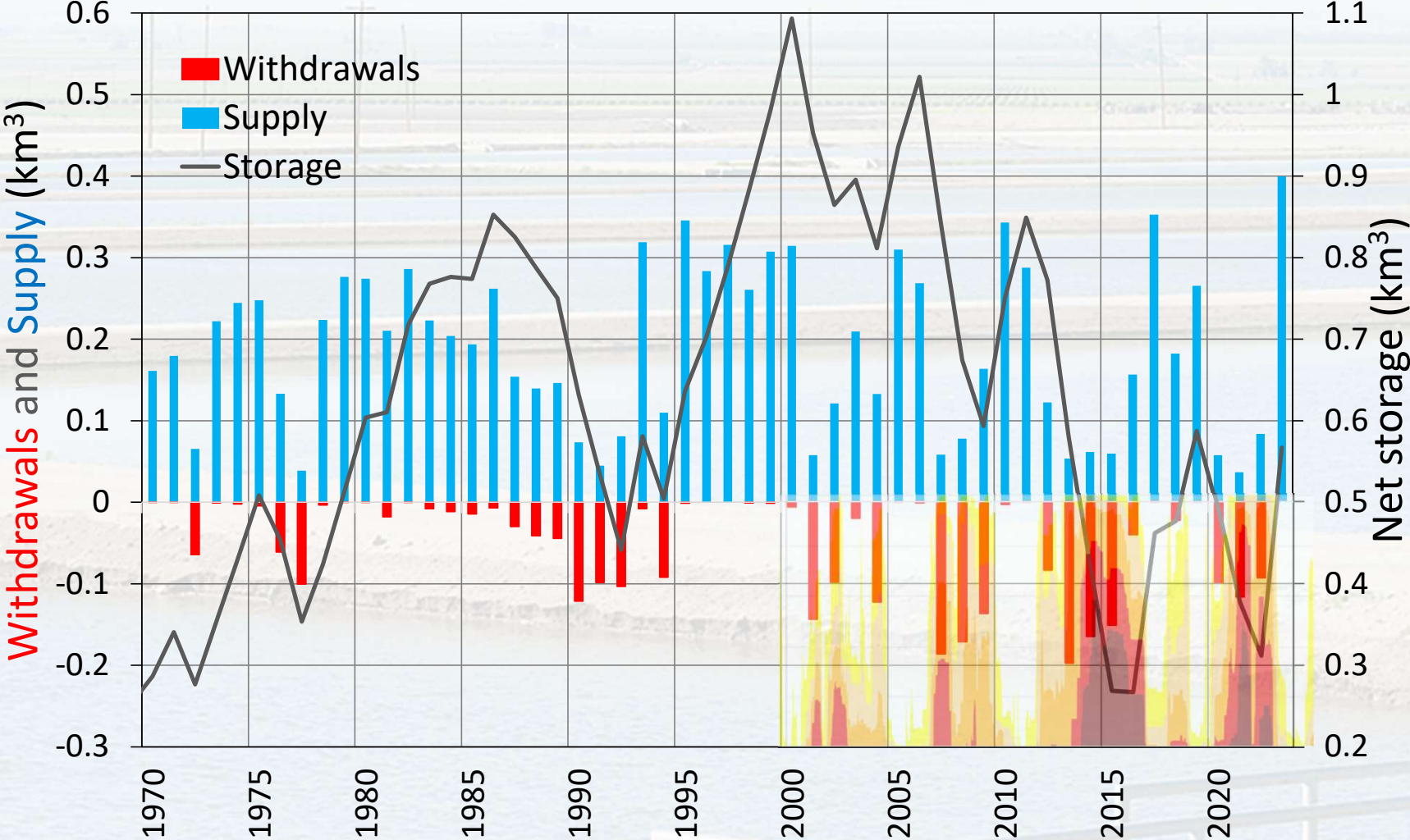
3d. Managed Aquifer Recharge in California Central Valley



3d. Water Budget in **Arvin Edison** Irrigation District, Central Valley, California

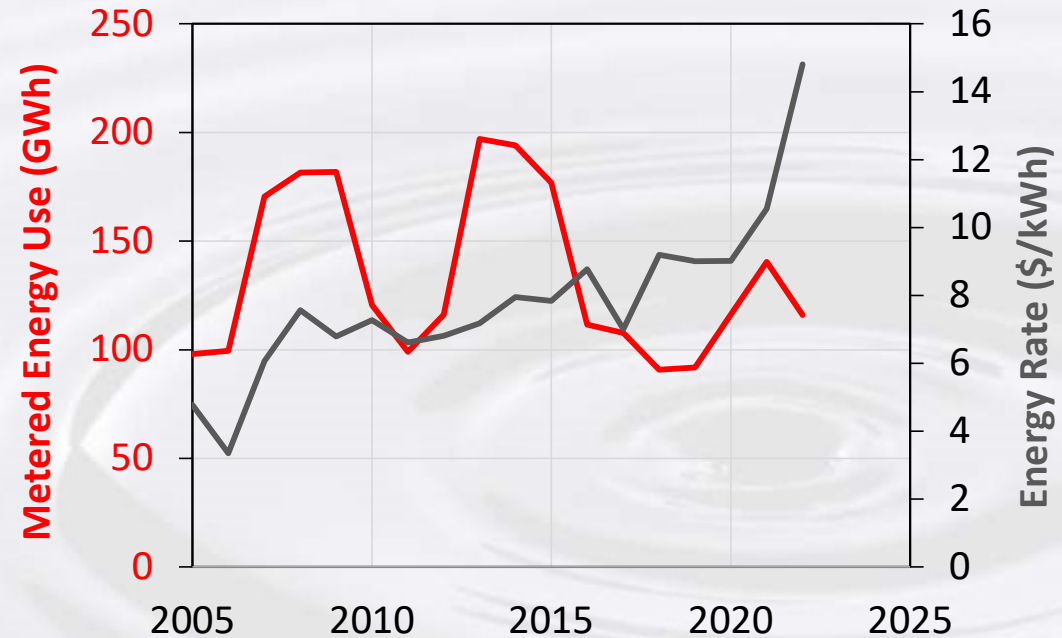
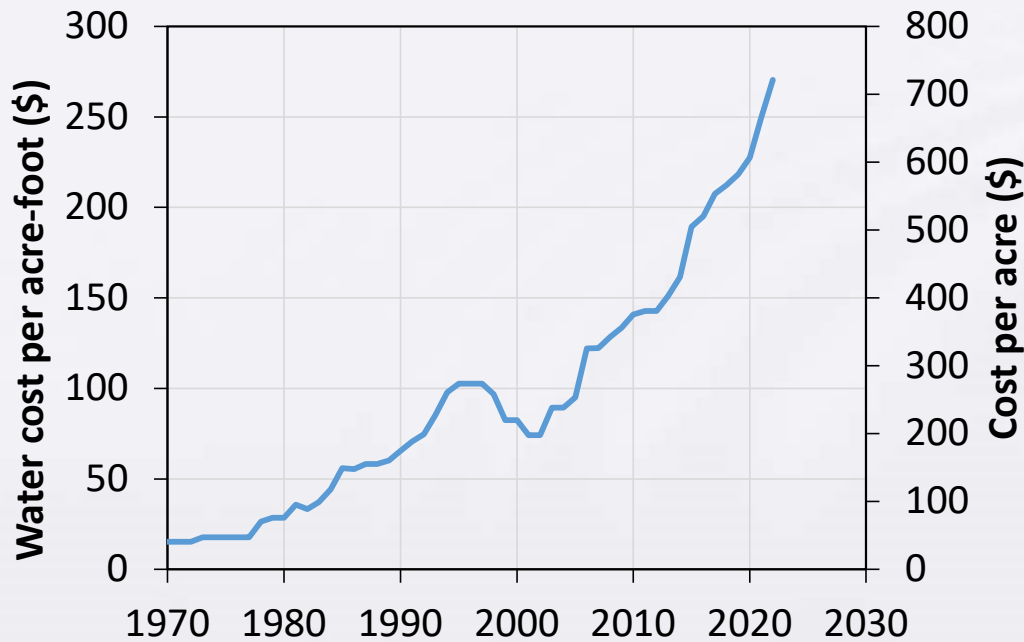


3d. Water Budget in **Arvin Edison** Irrigation District, Central Valley, California



- None
- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)

3d. Increasing Cost and Energy Intensity of Water at Arvin Edison



Water costs increased from \$5/af in 1990 to \$270/af in 2022

Power costs increased from \$3/af in 1970 to \$81/af in 2022

Power = 40% of cost in 2022

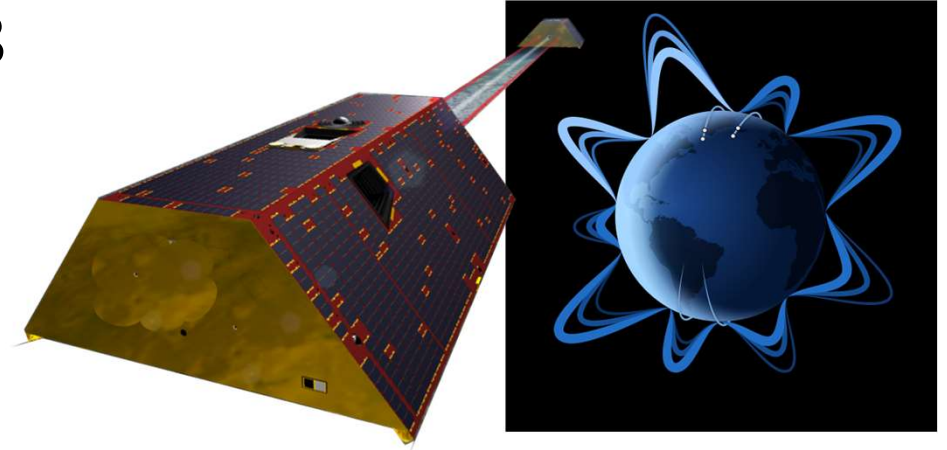


GRACE Continuity (GRACE-C)

Target Launch: 2028

Project/Program Constraints

- Partnership between NASA & DLR
- Similar design to GRACE (F0)
- Baseline design life: 2 years (7 years consumables)
- Orbit: 500 km altitude, 89° Inclination



Mission Science

- Mass Change produces observations consistent with the GRACE(F0), documented in the baseline Mass Change Designated Observable study

Measurement System

- Satellite to Satellite Tracking:
 - Laser Ranging Interferometer
 - Accelerometer
 - GNSS Receiver
 - Star Camera Attitude determination

MAGIC: Mass change And Geosciences International Constellation

European Next Generation Gravity Mission
(NGGM): Target Launch: 2032

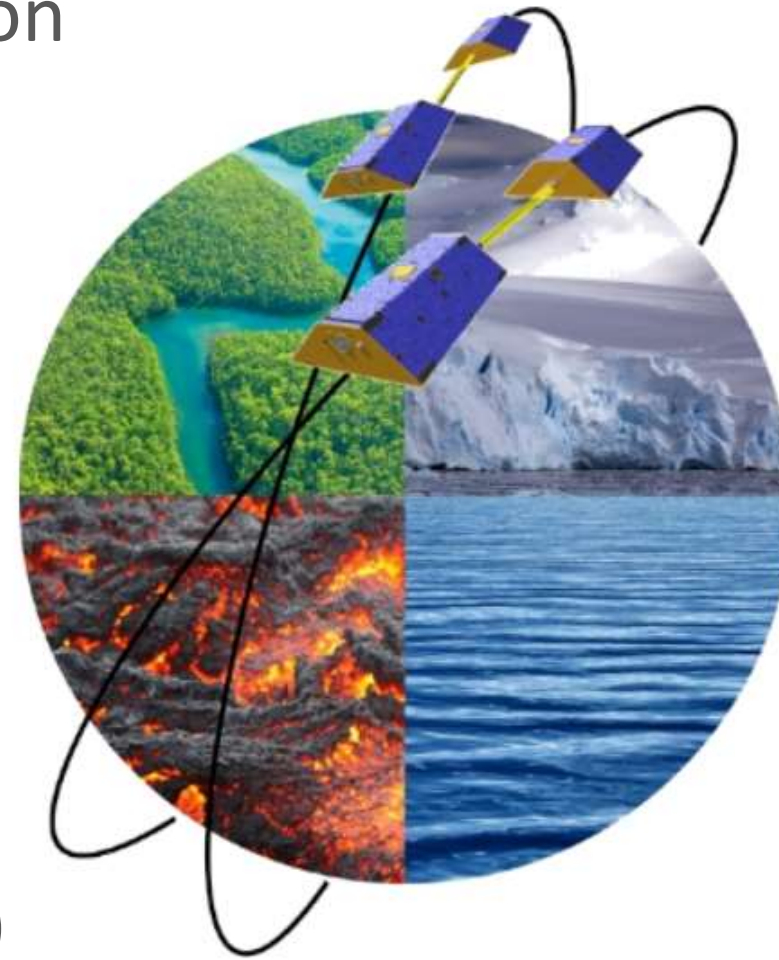
Resolution:

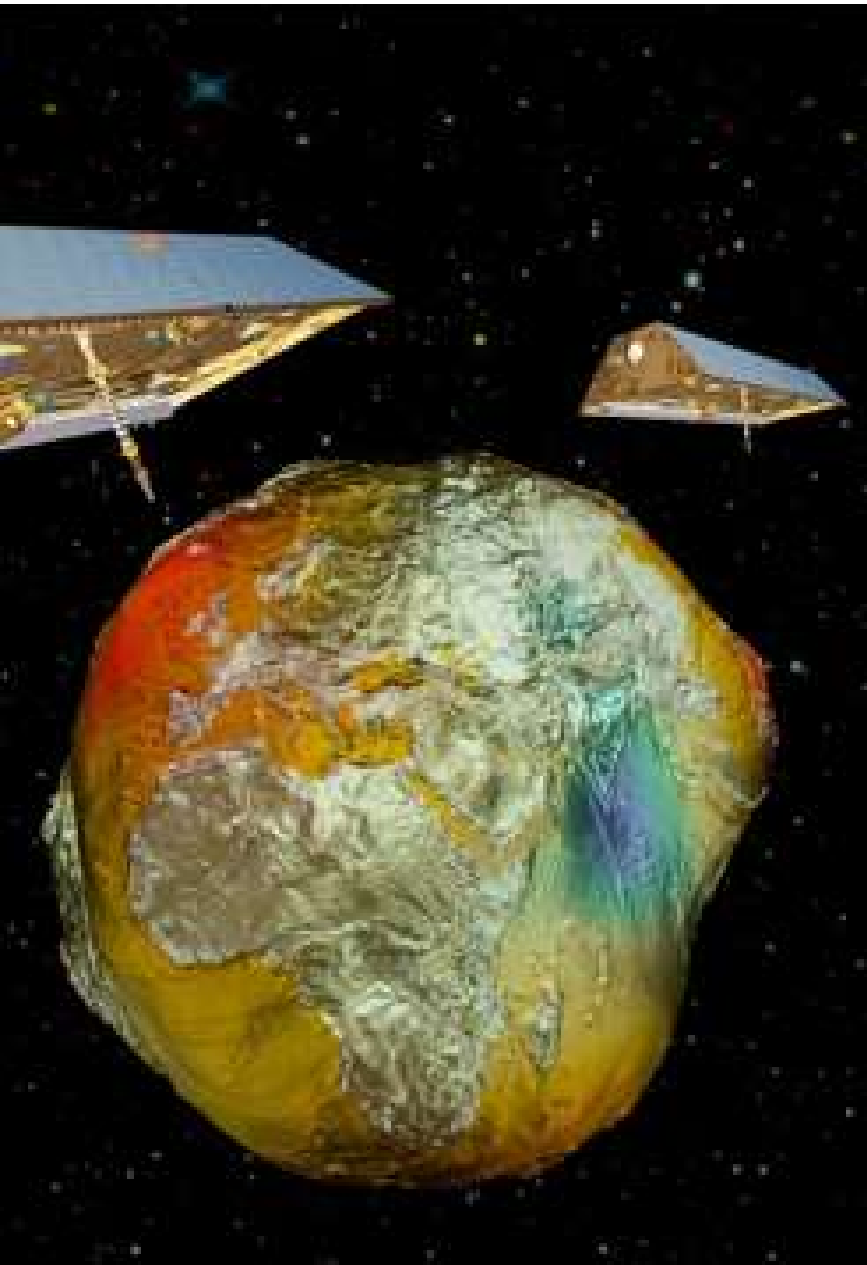
400 km elevation, 70° inclination

Wiese et al., 2022: trade space considering
spatiotemporal resolution and uncertainty;
Monthly solution ± 20 mm uncertainty

↑ resolution of TWSA from **350 km to 200 km**
(120,000 km² to 40,000 km²)

GOCE satellite: 250 km elevation (2009 – 2013)



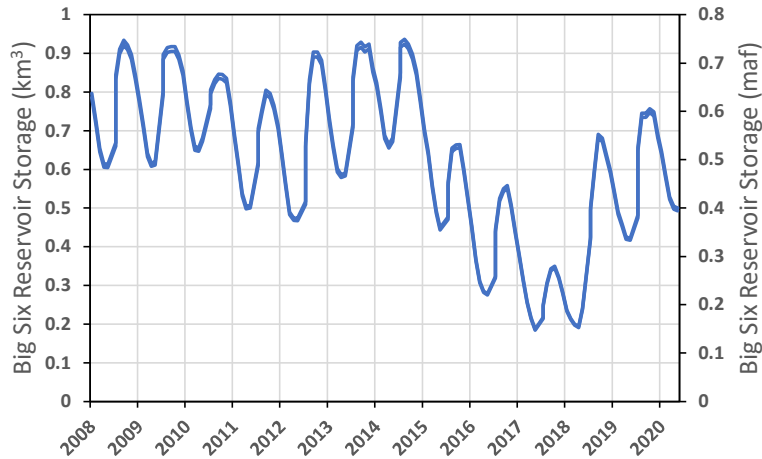


Outline

1. Background
2. Global water resources using GRACE
3. Irrigation
 - a. Increase irrigation in Sub-Saharan Africa
 - b. Switching from SW to GW irrigation (Pakistan, NW US)
 - c. Conjunctive use of SW and GW (CA Central Valley)
 - d. Managed Aquifer Recharge: Arizona
4. Urban water shortages (Cape Town, Sao Paulo)

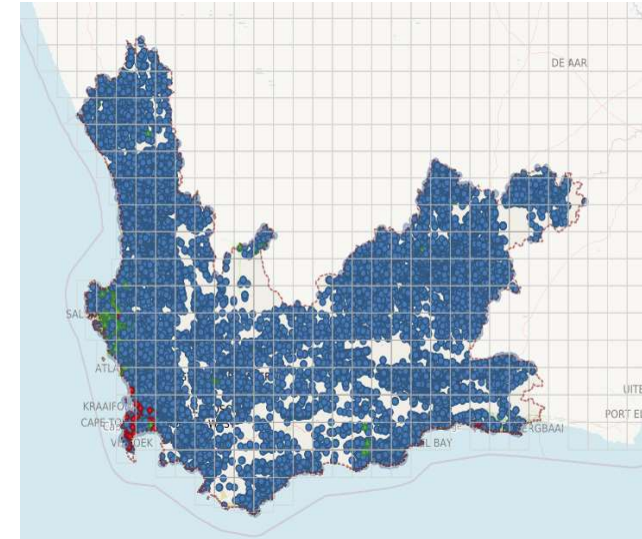
4.0 Cape Town Day Zero (13.5 % reservoir capacity), drought linked to El Nino, 70% increase in population (1995: 2.5 M – 2015: 4.1 M), water storage only ↑ed 17%

Western Cape Water Supply System

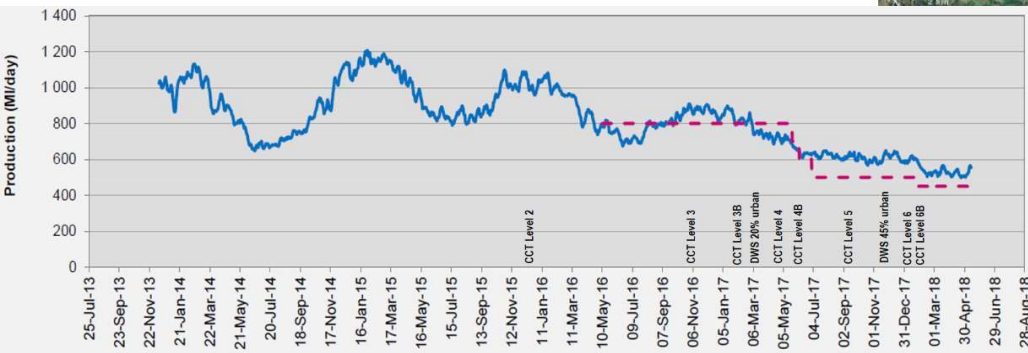


Heavily reliant on SW
Reservoir storage ↓
90% (2014), 50% (2015), 20% (2017)

Theewaterskloof Reservoir:



Expansion of GW:
Hundreds of boreholes drilled
Dept. Water and Sanitation:
encouraged households to drill
GW wells, Non-revenue water



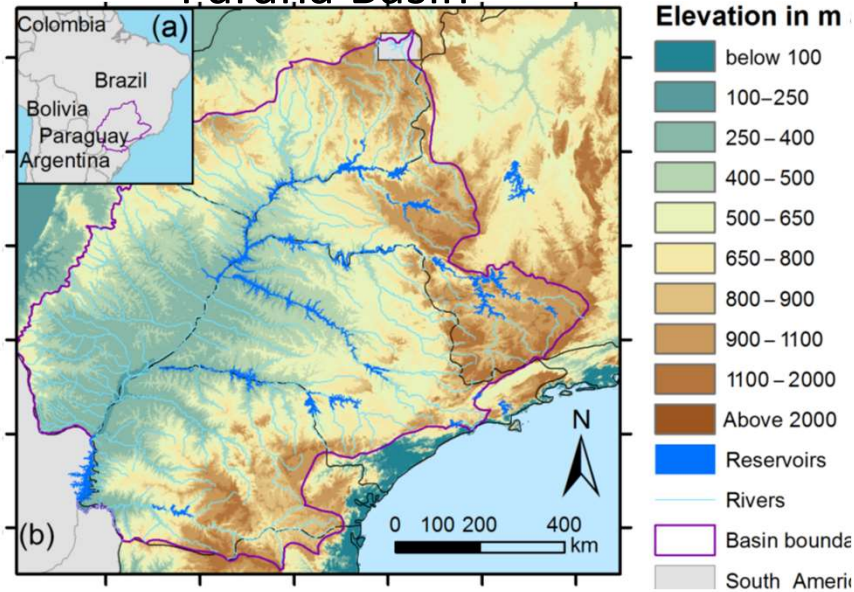
↓ demand
1200 MLD (2015) to
500 MLD (Jan 2018)

Agriculture highly impacted:
3000 jobs lost, 44% ↓ in yield.
No compensation for farmers.

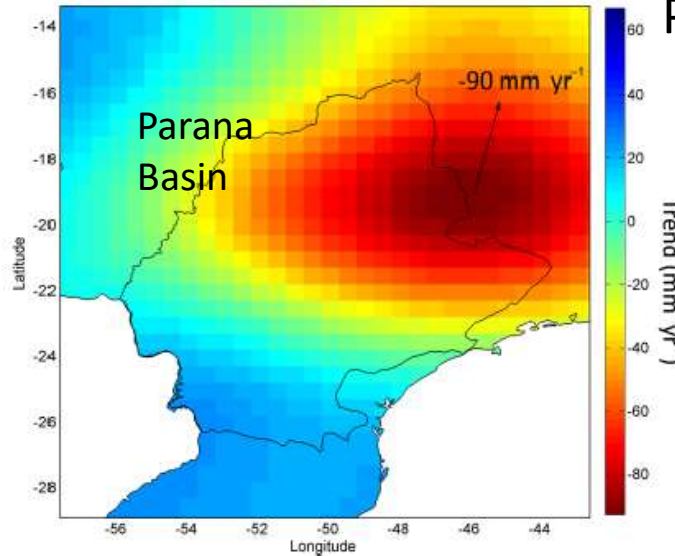
Livable Urban Waterways:
GEOSS project

4.0 Sao Paulo Drought

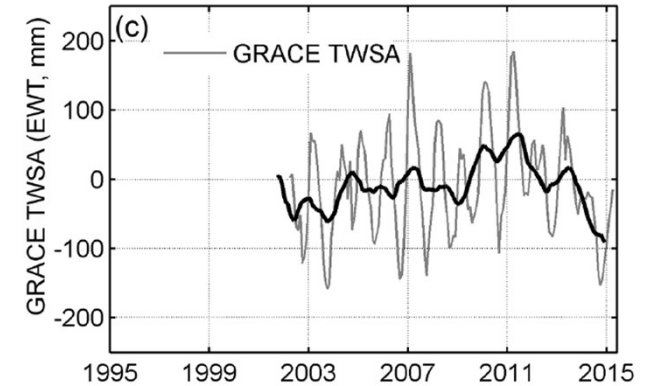
Parana Basin



GRACE TWS Anomaly (Apr. 11 – Apr. 2015)



GRACE Total Water Storage Trends (2011 – 2015) in Parana Basin



TWS depletion: 148 km³ total

2014 – 2017 drought linked to El Nino

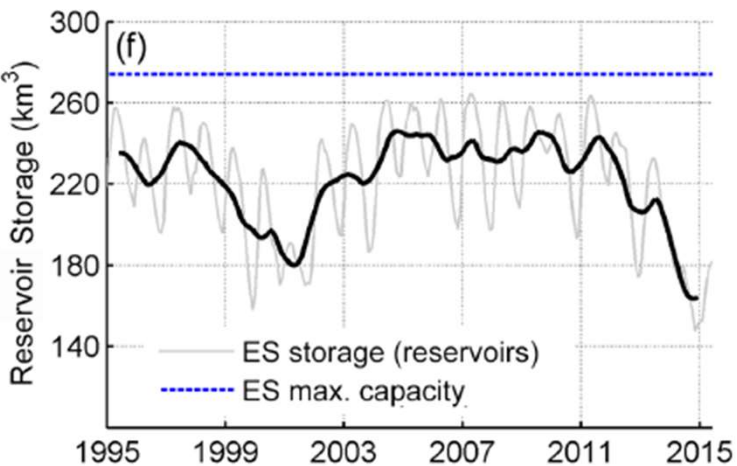
Sao Paulo: SW dominant water source for ~ 20 million people

GW ↑ed drought resilience: 10,000 – 12,000 private wells drilled

GW use increased from 1% to 25% of total water supply during drought

60% of wells not regulated. Non revenue water

Melo et al., HESS, 2016



Key Takeaways

1. **GRACE** data provide global picture of Total Water Storage anomalies but only for 2002 – 2025
2. **Irrigation:**
 - a) **↑ GW-fed irrigation in SSA**, switching from native vegetation to cropland ↑ed recharge
 - b) **Unmanaged aquifer recharge** is important, inefficient SW irrigation recharges GW (Ag-MAR, Flood-MAR) (Pakistan, NW India, NW US)
SW irrigation, salinization, waterlogging → transition to GW irrigation → conjunctive use
 - c) **GW and SW:** a single resource, need to be managed together
Conjunctive use of SW and GW in CA, AZ, -→ increase sustainable management
 - d) **Managed Aquifer Recharge:** highly successful in CA, AZ, ID, drought mitigation, irrigation infrastructure, suitable geology
3. **Urban water shortages:**
 - Cape Town and Sao Paulo, heavily reliant on surface water reservoirs
 - Expanding GW use, decentralization, non-revenue water

Water Resources Podcast

<http://wrp.beg.utexas.edu>

Apple, Spotify etc

Water Issues in India and Africa



Alan MacDonald

Alan MacDonald describes a recent study quantifying increases in groundwater storage in NW India and Central Pakistan over much of the last century and also the potential for groundwater to support development in much of Sub-Saharan Africa.



Groundwater Resilience to Climate Extremes/Change in Tropical Africa



Richard Taylor

Richard Taylor discusses linkages between rainfall extremes related to ENSO and episodic groundwater recharge, and how amplification of rainfall extremes under climate change may increase groundwater resources in Sub-Saharan Africa.



Assessing the Barriers to Groundwater Development in Sub-Saharan Africa



Jude Cobbing

Jude Cobbing discusses the water resources in Sub-Saharan Africa, the barriers to development, including financing, drilling and pumping technologies, and energy access, and approaches to addressing these barriers as shown in South Africa.



Groundwater: Achieving Global Development Goals



Karen Villhuth

Karen Villhuth discusses importance of groundwater in achieving the United Nations Sustainable Development Goals related to water and food security with particular emphasis in Sub-Saharan Africa.



Role of Groundwater in Developing Countries in the World Bank



Francois Bertone Lucy Lytton

Francois Bertone and Lucy Lytton discuss the recent World Bank report on The Hidden Wealth of Nations, The Economics of Groundwater in Times of Climate Change



Locating Groundwater Wells in Refugee Camps in Eastern Chad using Near-Surface Geophysics



Chad Groundwater Well Team

Paul Bauman talks about his recent trip to Eastern Chad to locate groundwater wells in new and expanding camps hosting refugees from neighboring Sudan.



Improving Access to Water for Tens of Millions of People in E. Africa and S. Asia



Rob Hope

Rob Hope discusses REACH and Uptime programs that are designed to improve water access for the poor in Ethiopia, Kenya, and Bangladesh.



Drought Forecasting in East Africa



Chris Funk

Chris Funk talks about drought forecasting in East Africa, with the sixth consecutive drought projected for spring 2023. He describes their improved forecasting skill with up to 6 month forecasts allowing agencies to work together to prevent famines.



Addressing Groundwater Scarcity and Arsenic Pollution with Potential Solutions in India



Abhijit Mukherjee

Abhijit Mukherjee discusses overexploitation of groundwater resources and arsenic contamination with potential solutions using managed aquifer recharge and stratified drilling to minimize arsenic exposure.



Bengal Water Machine



Mohammad Shamsudduha

Mohammad Shamsudduha (Shams) discusses the Bengal Water Machine, where seasonal groundwater depletion from irrigation creates space for increased recharge during summer monsoons in Bangladesh, capturing up to 90 km³ over 30 years.



Linking Water Resource Assessments and Policy to Develop Solutions in India



Veena Srinivasan

Veena Srinivasan talks about water resource challenges in southern India and linkages to suitable policies considering climate extremes.



Beyond Cape Town Day Zero: Strategies to Increase Water Resilience



Dale Barrow

Dale Barrow discusses increases in groundwater development and other strategies to enhance water resilience in Cape Town.



South African Lighthouse of Hope from Nature-Based Wastewater Treatment



Kevin Winter

Kevin Winter discusses nature-based approaches to treating informal settlement discharge for use in agriculture and other sectors.



Groundwater Resources in Brazil and Potential for Global Food Production



Edson Wendland

Edson Wendland describes major aquifers in Brazil and potential expansion of irrigation for global food production.



The Groundwater Resources for Drought Resilience in Urban Areas of Brazil

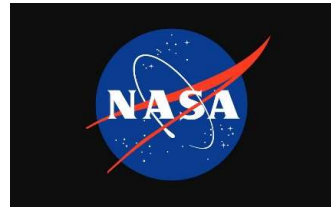


Ricardo Hirata

Ricardo Hirata discusses the role of groundwater in Brazil, emphasizing urban regions and their resilience to drought.



Sponsors:



Fisher Endowed Chair
in Geological Sciences

THE UNIVERSITY OF TEXAS AT AUSTIN

JACKSON

SCHOOL OF GEOSCIENCES

Bridget.Scanlon@beg.utexas.edu



BUREAU OF
ECONOMIC
GEOLOGY

