**Platform 1 – Geological Resources**

**Advanced modelling tools for improved groundwater management**

New Zealand's groundwater resources are at increasing risk of contamination and depletion from increased land use, population growth and climate change. Management and restoration of groundwater resources is particularly challenging because groundwater systems cannot be directly observed. Moreover, key system attributes (e.g., rate of recharge) and attribute uncertainties are difficult to quantify. This makes it difficult to properly evaluate and mitigate risks because the decision-making process needs to consider all of the uncertainties involved. To help overcome these challenges, the Advanced Framework for Groundwater Modelling project has developed a range of new modelling tools that allow practitioners to rapidly build groundwater models, including the uncertainties. These tools are already being used to support decision making in management of groundwater resources under increasing pressures of contamination, increased water use, and sea level rise.

In line with the strategic intent of this platform and the SSIF Groundwater programme, the newly developed tools enable groundwater resource managers, communities and iwi/Māori to ultimately make more informed, risk-based decisions on the sustainable management of groundwater resources. This, in turn, will help to improve the health of associated surface waters, ecosystems and communities.

This project has developed three sets of tools that together make model-based decision support more efficient, robust and accessible for groundwater managers and scientists in New Zealand and internationally. They allow practitioners to generate models, represent uncertainty in model inputs, and interpret, visualise and communicate the results more quickly and consistently than before. These tools include:

(1) The Iterative Ensemble Smoother, an algorithm which efficiently quantifies and reduces uncertainty in models by incorporating uncertainty in physical properties and processes and reducing the misfit between model results and observations of the real-world system. This algorithm has been incorporated into the internationally recognised parameter estimation and uncertainty quantification software platform PEST++. The efficiency gains this tool provides are remarkable, allowing the representation of uncertainty for hundreds of thousands of parameters at a fraction of the computational cost compared to traditional methods. These efficiency gains provide an acknowledged step-change in the groundwater modelling industry.

(2) A suite of software tools (FloPy, SWN and pyEMU) to facilitate rapid construction of models for risk-based decision analysis. The construction of groundwater models is often a laborious process that typically needs to be repeated and refined to answer specific management questions. FloPy enables the exploration and testing of model assumptions, and the rapid and consistent build of groundwater flow and transport models used for decision support. The Surface Water Network tool SWN enables rapid and flexible representation of surface water interactions with groundwater systems at variable resolution, which is crucial for effective water management. This tool has recently been implemented in several groundwater models, including the Ruataniwha groundwater model for Hawke's Bay Regional Council; a national scale groundwater model adapted for the New Zealand Water Model (NIWA); and the National Groundwater Age Model developed in the Te Whakaheke o te Wai Endeavour programme by GNS Science. New methods developed in pyEMU allow practitioners to quickly integrate diverse models with the parameter estimation and uncertainty analysis tools in PEST++. This functionality facilitates better representation of the

uncertainty inherent in natural groundwater systems and allows assimilation of the large and diverse data sets typical of real-world groundwater systems.

(3) A novel suite of tools designed to help non-modellers to interrogate groundwater model results and uncertainties quickly and interactively, and to communicate complex model outputs to decision makers and stakeholders. These new methods have been successfully applied in the Hauraki Plains and Waikato catchments for the Waikato Regional Council.

These tools were developed and tested in collaboration with other programmes. SSIF funding (50%) contributed to tool development, while Endeavour funding (50%), through the Te Whakaheke o te Wai, NZ SeaRise and Future Coasts programmes, focussed on testing and refinement of the tools in real-world applications.