Predicting environmental sustainability for proposed irrigation schemes

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Abstract

We have developed an innovative approach for predicting the environmental sustainability of proposed irrigation schemes on rivers. There are three key elements to this approach. First, the water resource potentially available to be taken for out-of-stream use must be defined by setting a river flow regime that sustains in-stream and other environmental values. Second, the capacity of the environment to support intensified land-use must be evaluated, by predicting effects on water quality and related values, and identifying ways to mitigate adverse effects. Third, the predictions must be integrated in a way that allows iterative adjustment of the proposal and assists decision-makers with the holistic evaluation of positive and negative effects. We trialled the approach for a proposed irrigation scheme that would divert 20 m^3/s from the Waitaki River, Canterbury, New Zealand, to irrigate 40,000 ha of pasture. This river has a mean annual flow of 369 m^3/s downstream of a large hydropower dam. Water is used for irrigation and environmental flows, as well as electricity generation. Under New Zealand legislation an assessment of environmental effects (AEE) is required for proposals to use natural resources. Our team of scientists, engineers and planners collaborated to prepare an AEE for the proposed irrigation scheme. Predictive models were coupled in novel ways to achieve integration between the technical disciplines. For the first time in New Zealand we were able to make quantitative predictions of key cumulative effects at the catchment scale, of both the water abstraction and the use of water for irrigation. The predictions were integrated and the proposal adjusted to achieve a balance between the needs of conflicting values. This approach should achieve better information about the true environmental costs of alternative future water use scenarios and thus lead to

better decisions on the environmental sustainability of irrigation proposals.

Keywords: environmental impact assessment, irrigation management, river flow regime, water quality, land use intensification

1 Introduction

Achieving sustainable management of the quantity and quality of freshwater is both a high priority and a serious challenge for most countries worldwide [1]. In New Zealand, a recent review of environmental performance by the Organisation for Economic Co-operation and Development (OECD) [2] concluded that two of the country's major environmental pressures, agriculture and energy production, have expanded in the last ten years resulting in a significant increase in the use of water, fertiliser and pesticides. They concluded that, while the use of water and fertiliser in New Zealand is still on the low side for OECD countries, water quality in rivers and lakes has declined in regions dominated by pastoral farming. About half of the total length of New Zealand's rivers occurs in these areas [3], and in lowland areas high nutrient inputs and microbiological contamination have regularly exceeded national guidelines [2]. Subsequently the New Zealand Ministry for the Environment's own environment report has highlighted the decline in water quality caused by intensifying agricultural production, together with global climate change, at the top of its list of environmental challenges [3].

Water managers in New Zealand have witnessed a recent explosion in the demand for water for both irrigation and hydroelectricity generation. Both of these uses have the potential to cause large-scale changes to the environment in New Zealand. With increasing pressure on water allocation decisions, it is becoming well recognised that there is a need for robust methods of predicting the full environmental consequences of alternative future scenarios for water use.

2 A brief history of changing approaches

In the days before much thought was given to environmental sustainability, decisions about large scale irrigation schemes were based largely on the available volume of the water resource and the economics of transferring that water to irrigate land. Often all of the water in a river was considered to be available for abstraction. This approach had obvious and immediate effects on the river environment. All in-stream values, including aquatic ecosystems, recreation, visual landscape, cultural and social values, were lost or significantly altered. Little thought was given to the effects of using water to change the use of land, other than the economic benefit.

Predicting the environmental effects of the abstraction of water from a river requires determination of the amount of flow that needs to be left in the river in order to sustain in-stream values at a satisfactory level. In the last 30 years a range of methods have been developed for predicting the in-stream flow requirements of river geomorphic processes, aquatic ecosystems, recreation activities, landscape and cultural needs, while contemplating an abstraction for economic and social needs. An entire field of science and engineering continues to develop and advance these methods today, e.g., [4][5][6][7].

Predicting the environmental effects of using water for irrigation requires consideration of the potential adverse effects of land-use intensification, such as degraded water quality and ecosystems, changes to landscape, cultural and social values, as well as economic and social benefits [8]. In the last 10 years technical methods for predicting these effects have advanced rapidly, e.g., [9][10][11][12].

Until recently, decisions on the allocation of water from rivers in New Zealand were based largely on consideration of the effects of the abstraction from the river. The potentially adverse effects of water use were considered separately and generally less comprehensively. One reason may be that land-use intensification effects are cumulative, only appearing some time after numerous separate water allocation decisions have been made, and often in different locations to the source of the water. Another reason is that in New Zealand, as in many countries, water and land resources have traditionally been managed by separate authorities and under separate pieces of legislation, albeit with some recognition of the inter-relationship between the two resources.

In New Zealand the Resource Management (RM) Act (1991) has facilitated closer integration of water and land management but it has taken time for practitioners to implement effectively [13]. The result is that environmental effects of both the abstraction of water and the use of that water are now being considered together in water allocation decisions.

3 A contemporary approach to environmental sustainability

Today's approach to predicting environmental sustainability for irrigation proposals is concerned with both water quantity and water quality. It is concerned with how much water is left in the river, as well as the amount of water applied to land and the consequences of the land-use changes that result. Environmental sustainability today encompasses a holistic consideration of effects on a wide range of values, including aquatic biodiversity, recreation, landscape, cultural and social values, as well as economic and community interests, e.g., [14]. Assessing environmental sustainability requires professionals from multiple technical disciplines in planning, science and engineering, as well as participation by the community at large. The challenge is to find ways of predicting the effects of change on all elements of the environment and then to integrate this knowledge to inform decisions about environmental sustainability.

We suggest there are three important elements to the contemporary approach:

i) Predict the effects of future water abstraction scenarios;
ii) Predict the effects of future water use scenarios;
iii) Integrate the predictions to form a holistic assessment for decision-makers.

At the outset it is necessary to identify all of the technical work-streams that may be necessary to predict effects. Once the relevant technical experts are assembled, they can identify the predictive tools that are available, or that need to be developed, in order to predict effects in their area of expertise. The key to successful integration is recognising the specific role of the integrator(s) in the team. The role of the integrators is not only to assist the technical experts to identify effects and couple their predictive models between disciplines, but also to facilitate inter-disciplinary communication and relationship management. It is important that integration is not just a phase at the end of the individual technical assessments, but occurs throughout the predictive assessment. Effective integration allows the knowledge provided by each technical expert to be built upon by other experts. It also allows for knowledge feedback that can be used to alter the proposal to manage adverse effects as they are identified. Such an iterative process should tend to produce irrigation proposals that move progressively closer to being truly environmentally sustainable.

The key elements of our approach are illustrated in the following case study.

4 Case study: new best practice in New Zealand

4.1 Proposed Hunter Downs Irrigation Scheme

The proposed Hunter Downs Irrigation Scheme (HDIS) would divert 20 m^3/s from the lower Waitaki River to irrigate 40,000 ha of pasture (Fig. 1). The Waitaki River is braided with an average of seven braids across a 700m wide fairway (see [15]). It has a mean annual flow of 369 m^3/s downstream of a large hydropower dam. Water is already used for irrigation, environmental flows and electricity generation.

4.2 Legislative framework

The purpose of the RM Act is to promote the sustainable management of natural and physical resources. The Act defines the functions and powers of regional and territorial authorities in New Zealand. Regional authorities are responsible for the sustainable management of water, land and air.

The RM Act requires regional authorities to prepare regional policy statements and guides the preparation of regional plans that define policies, objectives and rules for the management of water, air and related land-use. Preparation of these plans must follow a prescribed public participation process so that the final documents reflect the local community's view on what constitutes the sustainable management of natural and physical resources.

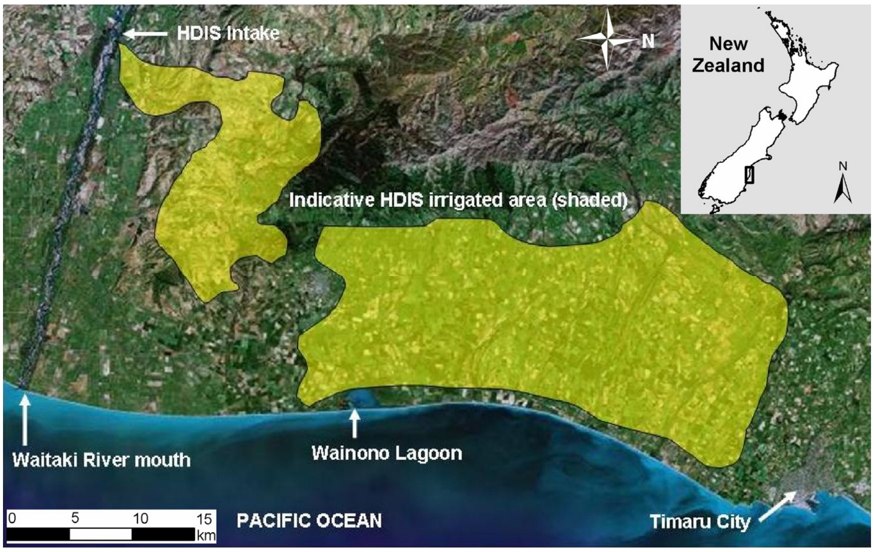

Figure 1: Satellite image showing location of the proposed HDIS (see [15]).

Anyone proposing to abstract and use water from a river, lake or groundwater must obtain resource consent from the relevant regional authority. The application for such consent must include an assessment of environmental effects (AEE) and consultation with stakeholders and the affected public. The application is considered by the regional authority under the framework provided by the RM Act and any relevant regional policy statements and plans. For decision-makers, the test of environmental sustainability is the extent to which the proposal meets the purpose of the RM Act and the regional policies and plan objectives.

4.3 Assessing environmental effects of the HDIS

A team of scientists, engineers and planners was assembled to prepare an AEE for the proposed HDIS. There were two technical work-streams that aimed to determine: i) a proposed sustainable water abstraction, by determining a sustainable river flow regime and thus the water that could be available for out-of-stream use; and ii) a proposed sustainable use of water, by determining the capacity of the environment to support intensified land-use, as well as the economic and social value of that water use. Reports were prepared documenting the methods, results and predictions for each technical discipline [16][17]. Our assessment approach, including the roles played by each technical expert and our integration process, is summarised in Fig. 2. The two technical work-streams and integration process are described in sections 4.4 to 4.6 using examples that illustrate key aspects of the approach.

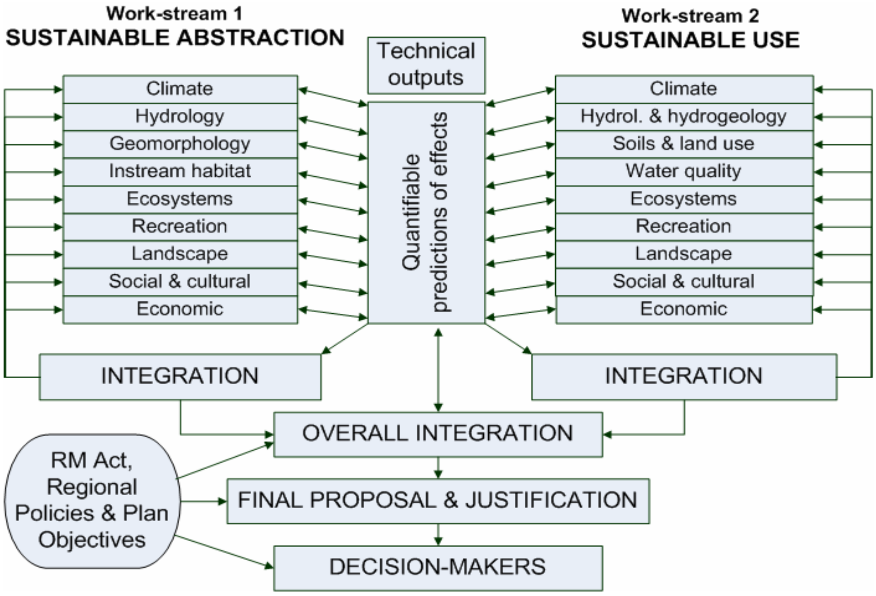

Figure 2: Concept diagram of technical work-streams and integration process.

4.4 Work-stream 1: Defining a sustainable water abstraction

4.4.1 Hydrology - climate variability and change

Understanding how river flow varies over days, seasons, years and decades, is fundamental for assessing how the existing flow regime supports current values, and for determining what irrigation abstraction might be sustainable. HDIS water abstractions and river flow were modelled for a range of future scenarios. The future scenarios included various combinations of irrigation abstraction, further hydro-electric power generation, and environmental flow regimes with rules requiring minimum flows, mid-range flow variability and floods. Various options for flow regime rules were modelled based on recommendations made by the other technical assessments (outputs from 4.4.2, 4.4.3 and 4.4.4). The hydrological data outputs for each scenario were used by technical experts in other disciplines for their predictive models (Fig. 2).

4.4.2 Geomorphology – sediment transport, flooding and coastal effects

Two-dimensional models, aerial laser scanning and aerial photography were used to predict likely geomorphic changes to bed substrate, braiding pattern, fairway width, tributary connectivity and behaviour of the river-mouth and adjacent coastline under future scenarios. This highlighted the importance of mid-range flows and floods for maintaining desired aspects of the river form.

4.4.3 Instream habitat for aquatic ecosystems

Instream habitat modelling methods were used to establish relationships between flow, and the area and quality of suitable physical habitat for aquatic species. Biological models helped to consider species interactions and seasonal life-cycle requirements. Predictions showed that a minimum flow ($150 m^3/s$) and elements of mid-range flow variability were important for aquatic ecosystems. The quantified reduction in aquatic habitat that occurred as water abstraction increased was compared with the associated economic and social benefit (4.4.6) of increased abstraction for the irrigator's reliability of water supply.

4.4.4 Wetland and terrestrial ecosystems

Relationships between river flow and wetland water levels were used to predict changes to wetland area under future flow scenarios, thus demonstrating the importance of a minimum river flow for maintaining hydraulically connected wetlands. Minimum flows, floods and vegetation control were shown to be important for maintaining braided river islands free from rodent bird predators and for creating bare fairway breeding habitat for endangered riverbed birds.

4.4.5 Recreation, landscape and cultural values

Effects on these values were assessed by experts using consultation techniques including surveys, interviews and public workshops, as well as knowledge of the physical (see 4.4.2) and biological (see 4.4.3) predictions of others (Fig. 2).

4.4.6 Economic, social and community effects

Economic and social analyses demonstrated the value of the HDIS to individual farmers and the local community as monetary value at the farm gate, value added to the regional economy, and increased levels of community well-being. Monetary value and social benefits depend on the reliability of water supply. Because reliability of supply is directly affected by the required minimum flow in the river, and this in turn affects the extent of river and wetland habitat area, landscape, recreation and cultural values, a link could be established between these latter environmental outcomes and the economic and social outcomes. This was crucial for the integration phase described next.

4.4.7 Integration and feedback-informed adjustment of the proposal

In addition to ensuring the coupling between technical disciplines, the integrators facilitated exercises where the whole project team weighed the identified negative and positive effects to inform adjustment of the proposal (Fig. 2). One example was the conflict between irrigators, who desired a highly reliable water supply to avoid hardship in dry summers, and the needs of aquatic ecosystems, whose habitat area is reduced by lower minimum flows. Being able to quantify the negative and positive outcomes allowed the project team to weigh these, decide where they felt the balance lay, and adjust the proposal accordingly. This decision involved value judgements, which will be discussed further in section 4.6. By way of example, this exercise resulted in a proposed minimum flow for the HDIS of $100 m^3/s$ instead of $150 m^3/s$, but only for a limited period (7%) of the time.

4.5 Work-stream 2: Defining a sustainable use of water

4.5.1 Scheme area hydrology, hydrogeology and soils

Scheme area hydrology, hydrogeology and soils were characterised to provide the basis for predictive methods of other technical experts (Fig. 2).

4.5.2 Land-use change scenarios

Experts considered soil mix, topography, capital costs and financial returns to predict future land-use mix scenarios if the HDIS scheme were to proceed. Key predictions were a significant increase in dairying and cropping, with corresponding reductions in dry-land sheep and deer farming.

4.5.3 Water quality: nutrients, sediment and micro-organisms

A nutrient budgets model was used to predict nitrate nitrogen leaching and dissolved phosphorus run-off from predicted land-use scenarios (outputs from 4.5.2 and 4.5.1). The outputs were coupled to a mass mixing model and used to predict increases to dissolved nutrient concentrations in groundwater, in rivers and in the local coastal Wainono Lagoon (see Fig. 1). Increases in sediment and micro-organisms in waterways were predicted qualitatively. Predictions showed that improved farm management practices could lessen water quality effects.

4.5.4 Aquatic ecosystems: rivers, wetlands and a coastal lagoon

Mass mixing model nutrient outputs (4.5.3) were coupled to an empirical model that predicted algae biomass would increase by 60% in rivers and 50% in Wainono Lagoon, with smaller increases for future scenarios that implemented improved farm management practices and riparian vegetation enhancement. The mass-mixing model also predicted increased flow, with associated positive ecosystem benefits, in some sections of some rivers.

4.5.5 Recreation, landscape and cultural values

The degraded water quality effects (4.5.3 and 4.5.4) had flow-on consequences for recreation, landscape and cultural values (Fig. 2). Increased algae growth would reduce visual aesthetics and be a nuisance for anglers. Reduced water quality and algae-smothered aquatic habitat degrades the *mauri* or ‘life force’ of waterways for maori people. In contrast, the predicted increase in flow for some river sections was a positive effect for angling, landscape and cultural values.

4.5.6 Economic, social and community effects

The identification of adverse environmental effects of intensified land-use led to a proposed mitigation package that is described in the next section. The cost of this mitigation to farmers was quantified to assist with the integration process.

4.5.7 Integration and feedback-informed adjustment of the proposal

The project team weighed the negative and positive effects of land-use intensification, just as was done previously for effects of the water abstraction on the river (Fig. 2). As a result a mitigation package was proposed that included: i) a mandatory requirement for farm management plans that defined efficient water use protocols, nutrient budgets and other on-farm actions; ii) financial incentives for riparian vegetation enhancement; iii) a contestable community environment enhancement fund; and iv) a robust environmental monitoring programme.

The benefits of mitigation measures were evaluated against the costs to farmers of implementing them. Furthermore, because some environmental degradation of waterways had already occurred due to past practices, it was recognised that some of these measures were desirable regardless of whether HDIS proceeded or not. The economic analysis showed there was doubt about whether the local community could afford to undertake, or would undertake, these measures if they did not have the additional income generated by the HDIS. All of these factors were considered by the project team when deciding on the financial quantum of these measures to be proposed to decision-makers (Fig. 2).

4.6 Overall integration: weighing the negative and positive effects

Deciding on what is truly environmentally sustainable involves value judgements about the relative merits of different values. Our iterative integration and proposal adjustment process (Fig. 2) involved value judgements by the project team that were not always agreed. The team used the relevant regional policies and plan objectives, as well as consultation with stakeholders and the affected public, to assist with this judgement, but it was the resource consent applicant (the project investor) who decided, based on advice from their expert consultant team, the nature of the final proposal put before decision-makers at a hearing.

While this process tended to produce an increasingly environmentally sustainable proposal, the ultimate test of environmental sustainability is a matter for decision-makers. To aid their evaluation at a hearing, we described a series of options that linked positive and negative environmental outcomes with social and economic outcomes. These were similar options to those the project team had used for their weighing exercises. The project investor highlighted its preferred option, but the alternative options were provided as context for the decision-makers and to assist their evaluation of the most environmentally sustainable option. Under the New Zealand legislative framework this would be the option that best met the purpose of the RM Act, regional policy statements and objectives of the relevant regional plans.

5 Discussion

At time of writing, a decision is still pending on the HDIS proposal. However, regardless of the decision outcome, the case study illustrates useful aspects of our approach. The environmental assessment process involved a large team of experts that was costly, but necessary for making informed decisions about the full range of potential effects, some of which could be very costly, or impossible, to reverse. Our approach (Fig. 2) can be scaled down for smaller proposals, with each of the technical disciplines being addressed at an appropriate level of detail for the likely scale and significance of effects. The multidisciplinary integration process is a key aspect, and can be undertaken with large or small teams. The iterative proposal adjustment process encourages the project investor to pro-actively address the broad spectrum of environmental sustainability at the project formulation stage, while reserving the final decision for independent decision-makers. This costs the project investor time and money, but their cost of not doing so is to risk environmentally precautionary decisions necessitated by inadequate information. In addition to these project benefits, each of the discussed aspects of our approach helps advance New Zealand's three national sustainability outcomes for freshwater [18]. The approach also aligns with United Nations (UN) Millennium Development Goal 7 (Ensure Environmental Sustainability) and relevant recommendations of the UN Millennium Project Task Force on Environmental Sustainability [14]. In this way our approach also addresses national and international policy goals for sustainable development.

6 Conclusions

Predicting the environmental sustainability of irrigation schemes requires a holistic approach to the assessment of effects of future water abstraction and use scenarios. Our approach has:

- Produced quantitative predictions of the positive and negative effects of the abstraction and use of water on a range of environmental values.
- Integrated the predictions and iteratively adjusted the irrigation proposal in an attempt to balance the needs of conflicting values.
- Provided decision-makers with a series of options that link environmental outcomes with social and economic outcomes, so that they may form a decision as to the most environmentally sustainable option.

This approach should achieve better information about the true environmental costs of alternative future scenarios and thus lead to better decisions on the environmental sustainability of irrigation proposals.

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