An integrated approach for modelling the impacts of land and water resource use in the Dak Lak plateau, Viet Nam[Ψ Φ]

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ABSTRACT

This paper describes an integrated approach developed to model the physical and related social welfare impacts of alternative water allocations in the Dak Lak plateau, Viet Nam. A physically based, distributed and integrated model of the plateau's surface and groundwater resources has been developed. This model distributively links hydrodynamics and water use decisions, in particular how the plateau's hydrology responds to different spatial configurations of cropping patterns, crop water allocations and urban water use. The outputs of this model will be compartmentally linked to economic modelling work in order to simulate distributive welfare outcomes resulting from different water allocation decisions over the short to medium term. The welfare impacts of alternative water allocations are being assessed for three "goods" – agricultural production, urban and environmental – using both revealed and stated preference approaches. This paper is a progress report on this modelling effort, detailing the objectives, approach and integration methodology and including discussion of some results to date.

Keywords: Hydro-economic modelling; environmental-economic modelling; land use; crop water production functions; choice modelling; contingent valuation

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The authors wish to acknowledge the assistance of the Ministry of Natural Resources and Environment, The Institute for Water Resource Planning (Hanoi), DHI Water & Environment and Dr Dave D'haeze from EDE Coffee International in the research work presented in this paper.

[Ψ] Research presented in this paper is part of the ACIAR funded project ADP/2002/015 'Managing groundwater access in the Central Highlands of Viet Nam'.

[Φ] Paper presented at AARES 50th Annual Conference, Sydney, 8-10 February 2006.

1 INTRODUCTION

In 2001 Viet Nam became the second largest coffee producer in the world. National production in 2004/2005 was approximately 870 thousand metric tons primarily of robusta variety (*C. canephora*), contributing approximately USD600 million towards Viet Nam's export earnings. Roughly 30 percent of national robusta output originates from the Dak Lak basalt plateau (the "DLP") in the Central Highlands. During the past twenty years the DLP has experienced widespread land transformation, predominantly in the form of forestland conversion to coffee plantation, and to a lesser extent to other cash crops such as rubber and black pepper. Rapid agricultural intensification and expansion has occurred in the DLP in a largely uncoordinated manner through spontaneous settlement and land conversion mainly by lowland Viet Kinh (Cheesman and Bennett, 2005). The result of these settlement dynamics is a dense mosaic of smallholder plots with the majority of farmers operating on areas of less then one hectare (Lenin Babu, et al., 2003, Ministry of Agriculture and Rural Development (MARD), 2003).

Expansion and intensification has resulted in spatial mismatches between land use and natural resource availability in the DLP (Ahmad, 2000, Dak Lak Peoples' Committee, 2001, D'haeze, et al., 2005, Ha, et al., 2001, Mai, 1999, Mueller, 2003, Nghi, 2002, Riddell, 1999, Tinh, 2003). In particular, there is growing evidence that the current levels of water use, particularly in the form of groundwater extraction rates, may not be sustainable, especially during dry years where pronounced water shortages and crop failures in the plateau have occurred (Ahmad, 2000, D'haeze, et al., 2005, Ha, et al., 2001, Riddell, 1999). Social, economic and environmental impacts of these water shortages are severe. For example, during the 2004 drought approximately 70,000 hectares of coffee was either lost or damaged in the Central Highlands region, river baseflows were reduced to approximately half of average dry season flows in large rivers. At the same time around 20,000 households experienced severe water shortages (Vietnam News Agency, 2004). Potential exists for water scarcity problems to increase in the future as the region continues to grow[2] on the back of agricultural intensification, state sponsored development of agro-processing industries and continued population growth from immigration combined with natural population increases.

During the past decade Viet Nam's water policy has ostensively shifted from an approach based on the development of supply-side capacity towards demand-side approaches. For example, the Law on Water Resources (LWR) (Socialist Republic of Vietnam, 1998) enacted in 1999 calls for the rational, efficient, fair and sustainable allocation of water resources. Further, Article 20 requires that regional water resource consumption be based on the 'real' potential of the water source. Where water demand assessments exceed the assessed supply potential, socio-economic plans must be adjusted based on actual supply capacity. As such, the national government's water resource legislation embodies both resource development and conservation objectives (Reichelderfer and Kramer, 1993). The resource development objective is to accelerate economic development by shifting the resource from lower to higher valued uses, while the resource conservation objective is to improve the efficiency of resource use by encouraging water use consistent with maximising long run net social benefits, implying a sustainable consumption path over time.

To implement water policy in Dak Lak that is 'efficient, rational, sustainable and fair' requires an understanding of the relationship between biophysical processes, regional socio-economic factors and the dynamic, physically distributed relationships between these systems. This paper describes an integrated, multi-disciplinary approach being developed to assess water resource management options in the DLP. The approach integrates compartmental biophysical and socio-economic analysis towards the objective of analyzing the spatially and temporally distributed impacts of water allocation policies using both simulation and optimization approaches. The ultimate objective of this work is to develop

[2] Between 2006-2010 Dak Lak's growth is projected at 8.6 percent per annum Dak Lak Peoples' Committee.

an understanding of the spatial distribution, direction and magnitude of shifts in social welfare resulting from alternative water allocation policies over the short to medium term in the DLP. Such an understanding will enable more effective interventions towards the objectives of 'efficient, rational, sustainable and fair' water resource management in the DLP. The approach employs both revealed and stated preference techniques to estimate the welfare contribution of water in agriculture, urban and environmental allocations. Simulation of multiple alternatives accounting for both exogenous impacts, such as natural variability, and endogenous ones, such as farm level irrigation practices, defines a range of estimated values from which an approximation of optimal allocation policies can be identified (Gomboso, et al., 1999).

The approach discussed in this paper is being developed as part of an ACIAR funded project in cooperation with local government ministries and universities in Viet Nam comprising a multidisciplinary team of hydrologists, agronomists, economists and social researchers. It is anticipated that the model will assist relevant agencies to better manage surface and groundwater resources in the DLP, in particular with respect to critical questions concerning the impact of different land use and irrigation practices on regional water availability. Current work is also exploring the best way to employed simulation outputs in participatory planning for local water resources at the irrigation, sub-catchments and watershed scale within the DLP. This approach is broadly consistent with integrated assessment frameworks (Letcher, et al., 2005), with the government's recently renewed focus on the importance of participatory management in irrigation schemes and natural resource management (Socialist Republic of Vietnam, 2004) and the subsidiarity principles that form the basis of the proposed Srepok River Basin Organization which the DLP is located in (Petersen, 2004). The work complements and draws on previous water resources work completed in the region, notably D'haeze, et al., (2005) and Moller (1997).

"Provincial Forestry Development Program of Dak lak. In period of 2001-2010." Dak Lak Peoples' Committee..

2 THE DAK LAK PLATEAU

The DLP covers an area of 2340 km^2, dominating the central region of Dak Lak Province, which is located approximately 350 kilometres northeast of Ho Chi Minh City[3]. The DLP forms part of the northern boundary of the Srepok river basin, one of the tributaries of the Mekong River, which originates in the southern highlands of Viet Nam and flows into Cambodia. The plateau is generally flat with low hills changing to undulating hills in the central plain region. Average elevation is from 350 meters in the west to 700 meters in the central region, with higher peaks located in the north-central region. Average annual precipitation is approximately 1,800mm for regions west of the central plateau's range and 1500mm to the east. Pronounced wet and dry seasons occur between May and November (wet) and December to April (dry).

A layer of highly fertile and well draining Rhodic Ferralsols of varying thickness up to 30 meters covers more then 90 percent of the DLP. This soil is the primary motivating factor behind the region's rapid agricultural expansion and intensification. Beneath this layer the geologic structure is complex and heterogeneous in both the horizontal and vertical direction. Conceptually however, the region's geology can be simplified into five hydrostratigraphic units, comprising three aquifers and two aquitards. Of these layers, the upper unconfined aquifer is the most important to the people of the DLP as it constitutes the primary water source for most irrigated agriculture and rural domestic water consumption through hand dug wells. Being comprised mainly of porous substances (rhodic ferralsols, semi-weathered basalt and porous basalt) means the hydrodynamics within the unconfined aquifer can be modeled with some confidence. An aquitard comprised or Jurassic granite separates the upper unconfined and lower confined aquifers. Drilling is needed to gain access to this lower source. The confined aquifer is composed of inter-disposed compact fractured and porous basalt, resulting in the existence of good 'deposits' of groundwater of uncertain supply reliability (Moller, 1997).

[3] Approximately located between 12°40'-13°00'N, 107°70'-108°20'E

Land use is dominated by intensive agriculture, predominantly the cultivation of robusta coffee, but also other cash crops and wetland rice. For coffee, a planting density of about 1,100 trees per hectare is commonly reported (D'haeze, et al., 2003) however some regional variability exists in this figure. Wetland rice is grown during the Winter-Spring season from November to March and the Summer-Autumn season from May to August. Maize is planted in both the Summer-Autumn and the Autumn-Winter crop season as a mono- and an intercrop with premature coffee, green beans (in the Summer-Autumn crop season), or with soybean or groundnut in the Autumn-Winter season. During the Summer-Autumn season, all crops are generally rainfed. In contrast Winter-Spring crops generally all requires irrigation. Different crops exhibit sensitivity to water stress during phenological stages, some of which coincide with Dak Lak’s dry season occurring between December and late April. Importantly, coffee requires between 340-600 mm of irrigation during the dry season to break flower bud dormancy and to induce fruit setting (COWI-Kruger Konsult, 1996, D'haeze, et al., 2003). Farm level irrigation practices may contribute towards water shortages in Dak Lak, with research suggesting farmers over-irrigate coffee by approximately 2.3 times the requirement for optimum yields and bean quality (D'haeze, et al., 2003). No firm evidence is available for irrigation on other crops, but discussions with local experts suggest over-irrigation is not exclusive to coffee in the plateau.

Table 1 Land Use, DLP 2000, 2002

Land Cover Type	Area					
	2000			2002		
	Hectares	Percent	Percent agric. area	Hectares	Percent	Percent agric. area
Coffee	130,785	55.18%	71.79%	128,974	54.14%	73.45%
Rubber, Cashew, Black Pepper	14,158	5.97%	7.77%	582	0.24%	0.33%
Paddy Rice	12,808	5.40%	7.03%	16,542	6.94%	9.42%
Annual crops (inc. upland rice)	24,429	10.31%	13.41%	29,504	12.39%	16.80%
Residential and water	36,693	15.48%		48,173	20.22%	
Forest and unused	18,143	7.65%		14,430	6.06%	
Total	**237,016**	**100.00%**	**100.00%**	**238,205**	**100%**	**100.00%**

Approximately 21 percent of irrigation water in Dak Lak is extracted from surface water stored in artificial ponds and water reservoirs (including water delivered through irrigation systems), 22 percent comes from natural rivers, streams and lakes and 57 percent is extracted from ground resources, primarily from dug wells in the unconfined aquifer (Luu, 2002 in D'haeze, et al., 2005). Because a large percentage of surface water used in irrigation originates as baseflow from groundwater seepage, it is probable that in practice the contribution of groundwater towards sustaining livelihoods in the plateau is much higher then these figures suggest.

The inherent uncertainty in the reliability of the lower confined aquifer supplies, combined with drilling costs have dissuaded the majority of small scale farmers from accessing this resource, however it is used by some larger state run farms and to supply large urban centers such as the regional capital Buon Ma Thuot (BMT). The location of privately dug wells accessing groundwater in the unconfined aquifer have not been systematically surveyed however high well density of approximately one private dug well per hectare has been reported within the region in earlier research (Ahmad, 2000). This figure varies across the plateau depending on the availability and reliability of substitute sources and the depth of the basalt layer to the first aquitard.

Heavy reliance on groundwater for irrigation and urban consumption highlights the importance of the spatial distribution of annual wet season rainfall, which recharges the unconfined aquifer. Seasonal recharge results in pronounced fluctuations in wet/dry season average head elevation, between two and ten meters in the unconfined aquifer depending on location. The stochastic distribution of rainfall-based recharge in the DLP is important not only because it recharges the unconfined aquifer system on which majority of small-scale farmers in the plateau are reliant, but also because it is integral to determining the level and distribution of dry season baseflows and consequent dry season recharge to reservoirs (Moller, 1997). These dry season flows to reservoirs in turn define the volume of water available to irrigation schemes and their cost-effectiveness. Further, the distribution of the wet season rainfall is a key determinant of (at least) coffee farmers' irrigation decisions. For example, after a “dry” wet season farmers will generally irrigate earlier in the year and will apply greater volumes to ensure fruit setting (D'haeze, 2005); the distribution of this behaviour is likely to impact on regional hydrodynamics.

Outside irrigation systems in the DLP, the supply and extraction of water for irrigation is unregulated. Given that over 85 percent of all irrigation water is open access, the design of effective water resource management in the DLP is problematic and presents limitations to achieving efficiency gains through water transfers. Combined with evidence of over-irrigation of the region’s dominant crop and the probable over-irrigation of other annual and seasonal crops, farm level water use efficiency is a central focus of this research as it has the greatest demand side influence on hydrodynamics in the DLP. If it can be demonstrated to farmers that increased water use efficiency can be achieved with no loss in yield or yield quality, and potentially a gain in net profitability as a result of reduced pumping costs and effort, this information should encourage water conservation. Based on the assumption that ‘more water in the aquifer system is better’, Pareto improved outcomes are anticipated. The objective of the integrated modelling system is to demonstrate the potential for alternative water use arrangements.

3 MODELLING PRINCIPLES AND COMPONENTS

The integrated assessment approach adopted in the research is based in a general set of principles (Letcher, et al., 2005, Turner, et al., 2004: x-xi)

(1) **The principle of economic efficiency and cost benefit analysis,** which requires the allocation of water should be made with an understanding of the full economic value of water in its alternative uses, including non-use values associated with functions such as the maintenance of functional diversity. In the absence of markets for water that accurately reflect the resource’s scarcity value via prices, the estimation of shadow prices based on estimates of consumers’ willingness to pay is required. Again, the objective of the cost benefit approach

when integrated with the hydrodynamic model is to understand the directions and magnitudes of change, based on biophysical parameters and social welfare, of alternative options.

(2) **The principle of integrated analysis,** involving integration of models, disciplines, issues, spatial and temporal scales of consideration and stakeholders (Letcher, et al., 2005). The integrated approach shifts from a narrow sectoral view to one that encompasses biophysical, socio-economic and organizational variables and their interrelationships;

(3) **The principle of extended spatial and temporal perspective,** which requires a developed understanding of the entire hydrodynamic system in order to understand the inter-temporal and spatially distributed impacts of alternative policy options. This contrasts with the analysis of a single component of this system such as a river or irrigation system; and

(4) **The principle of inclusion** to ensure that the approach addresses relevant issues and that the solution is based in multidisciplinary expertise.

Thematically, the modeling framework includes four components: (1) a deterministic hydrodynamic model that simulates ground and surface water dynamics given exogenously defined parameters such as meteorological conditions and land use patterns (2) a deterministic crop growth model that simulates yield response to water (3) a set of socioeconomic components that (i) defines the profit maximizing crop and irrigation allocation strategies at the farm level using non-linear programming, subject to parametrically variation in water availability and (ii) identifies shadow prices for water in urban and environmental allocations using stated preference modeling and (4) an integrating benefit cost analysis framework (BCA). The component models are discussed in detail in the following section.

3.1 BIOPHYSICAL MODELLING

3.1.1 HYDRODYNAMIC MODEL

The objective of the hydrological model is to represent the key hydrological processes that are impacted by economic agents' decisions at a level of detail sufficient to identify the distributed impacts of alternative outcomes given an initial state of nature. In the DLP, the region's heavy reliance on groundwater and the complex, heterogeneous hydrogeology precludes the use of lumped parameter or linked-lumped parameter spatial models that treat the aquifer as a single reservoir or a set of separate linked reservoirs (Gisser and Sanchez, 1980, Hellegers, et al., 2001, Knapp and Olson, 1995, Roseta-Palma, 2003, Tsur, 1997). Adopting a lumped parameter approach would over-simply the plateau's hydrodynamics and provide a result that would be meaningless for policy development. This is because such a model would be incapable of defining the distributed biophysical and causally linked social welfare impacts of alternative scenarios on surface and ground water resources.

The groundwater and surface-water dynamics of the DLP are therefore modeled using an integrated surface groundwater simulation modeling tool, MIKE SHE and MIKE 11 (DHI Software, 2005). MIKE SHE is a hydrological modeling system that describes the land-based hydrological system including groundwater dynamics, whereas MIKE 11 models dynamics of surface water systems. The model system is physically based, distributed and integrated. Being physically based implies that the system is based on the set of mathematical equations that describes the three-dimensional flow of water in the state space. Being distributed means the model allows for spatial variation in the parameters determining flow, while the integration allows the user to include the modules of interest in a given problem because exchanges between the components are accounted for in the model.

MIKE SHE and MIKE 11 model hydrodynamics based on a grid net approach with the level of resolution of each grid layer defined by the model developer. The model simulates the stock and dynamics of water in the vertical and horizontal dimensions based on the topography, land use, soil profile, hydrostratigraphic structure and other characteristics within each cell. Simulations are based on finite difference solutions of the partial differential equations that describe the processes of overland and channel flow, flow in the unsaturated and saturated zones, interception and evopotranspiration at differing time steps (Singh, et al., 1999). Grid nets can be lumped based on criteria defined by the developer, such as a land unit, defined as an area with homogenous land qualities and management practices (Food and Agriculture Organization of the United Nations, 1976). Lumping of homogeneous cells enables aggregated analysis of the distributive impacts of alternative land and water allocation scenarios within the plateau.

3.1.2 CROP GROWTH MODEL

A limitation of the MIKE SHE suite is that it does not explicitly model crop yield response to soil moisture in the root zone. It is well established that crop yields are sensitive to water shortages and that yield reductions differ between crops based on phenological (growth stage) sensitivity to water stress or duration (Allen, et al., 1998, Doorenbos and Kassam, 1979, Rao and Sarma, 1990). In some crops, small water deficits during a growth stage can contribute towards large reductions in harvestable mass, while in other crops large water deficits during some growth stages have little impact on final crop production. Approaches to modelling yield response to water may be based explicitly on yield-soil moisture relationships or can adopt more simplistic assumptions to approximate the relationship between applied water, evapo-transpiration and yield (Adkins, 1993, Kumar, et al., 1998, Salman, et al., 2001, Sethi, et al., 2002). Although some authors have suggested simplified models perform satisfactorily under deficit irrigation conditions (Kipkorir, et al., 2001), the limited empirical research in this area suggests that the use of these simplified models may result in inaccurate yield estimates under water deficit conditions (Ghahraman and Sepaskhah 2004). As a result, models incorporating soil moisture balance and yield production are employed in this research, given that deficit irrigation practices may be more profitable, especially during drought periods.

Two models are employed to assess crop yield soil moisture relationships. Robusta yield from productive trees in response to soil moisture dynamics are modeled using a deterministic one-dimensional model for robusta in Dak Lak developed by D'haeze, et al. (2003) in WAVE 2.1. This model has been demonstrated to accurately simulate flower bud development and fruit growth in response to soil moisture conditions after calibration to local climatic and soil conditions. The model has been calibrated with an experimental dataset from 2001 and validated against an independent dataset (2002). Further information on this model is available in D'haeze, et al. (2003).

Seasonal crops are modeled using a crop growth simulation model developed for this project to integrate with the MIKE platform (“CropGrowth”). The CropGrowth model is a one-dimensional, deterministic, physically-based soil-crop model, simulating the soil water balance, and the response of the crop to the availability of soil water. The function of CropGrowth is to calculate potential and actual crop yield [kg/ha]. This is achieved through the exchange of information between MIKE SHE and CropGrowth through an open source interface. On a weekly timestep, MIKE SHE provides CropGrowth with information on potential and actual evapotranspiration for each crop. In turn, based on irrigation occurring within the timestep, CropGrowth updates MIKE SHE with leaf area index (‘LAI’) and root depth in order to determine plant water uptake and adjust the soil moisture content of the root zone in the MIKE platform[4]. The model is calibrated for accuracy against farm survey data describing irrigation volumes and yield, from 2005.

3.2 ECONOMIC MODELLING OF HUMAN DECISIONS

The biophysical modeling discussed in the previous section defines resource flows and enables identification of causal relationships between changes in these flows and social welfare outcomes. Economic modeling aims to estimate values associated with changes in these resource flows to enable policy relevant comparisons. In the DLP, changes in resource flows impact both directly and indirectly on social welfare outcomes. Direct impacts result

[4] For more information see Cheesman, J. "An Economic Model for Optimising Agricultural Water Allocations in Dak Lak, Viet Nam." The Australian National University..

from using the water resources in production activities, modeled here to include agricultural production and household consumption. Indirect impacts result from passive use activities, modeled here as environmental flow allocation. Other values could also be modeled, such as the value of water in in-stream aquaculture or hydropower, however these activities operate on a small scale in the DLP and are therefore excluded from the analysis.

3.2.1 ECONOMIC MODELING OF FARM DECISIONS

The objective of the farm level economic modeling is to define crop specific, at-source, short-run, marginal values for irrigation water. At source means the model accounts for the delivery cost of the water and ensures agricultural water values are commensurate with in-stream uses (Young, 2005: 167). Adopting a short-term focus assumes capital (specifically land, capital and entrepreneurship in this model) is fixed and production outputs result from different levels of variable inputs. This approach is preferred to a long-run approach that allows for changes in capital due to the project's practical objective of identifying whether economic potential exists for irrigators to change behavior in the near term.

The value of irrigation water is derived from estimation of the marginal physical product for each crop given a defined irrigation schedule, initial soil moisture conditions, time series climatic parameters, and combined with estimates of factor input and output prices based on crop budget analysis. Separate applications of the estimation procedures are employed to define marginal values under (1) existing farm management and (2) optimal farm management practices.

To assess the marginal value of irrigation water under existing farm management practices, the residual method is employed to obtain estimates of net producer income attributable to irrigation water. Representative irrigation schedules and yields developed from the 2005 farm survey, are run in the WAVE 2.1 and CropGrowth simulators to define yields under different climatic and initial soil moisture conditions. Yields are combined with representative farm budgets to define net income attributable to water, the residual claimant. To account for establishment costs of robusta, a plant life of 25 years is assumed, including a four-year establishment period. Average establishment costs are amortized across the production period using a straight-line approach. Constant returns and fixed prices are assumed with the result that average and marginal irrigation water values are equated.

Evaluation of optimal farm and crop-level irrigation practices is achieved via a profit maximizing mathematical programming model treating land allocation and irrigation timing and volumes as endogenous. The model defines the optional allocation of irrigation water in terms of timing and volume and cropland allocation for each land management unit subject to parametric constraints on water and land availability. There are two motivations for this approach. First, given a stock of water available to irrigation, agricultural profits may be improved by changing cropping patterns and / or crops' irrigation schedules to achieve optimum profitability. Secondly, economic profits may be held constant by parametrically reducing the available water stock and changing cropping patterns and / or irrigation schedules[5].

A two-stage approach is employed to estimate the optimal irrigation and cropping strategy. In the first stage, for each annual and seasonal crop in the study region, multiple iterations of different crop growth-soil moisture-irrigation strategies are run in the MIKE SHE / CropGrowth modules. Outputs from this model are accumulated yield, soil moisture and irrigation volume obtained in five day time steps. These outputs are used to estimate econometrically soil moisture and crop yield response coefficients at each time step in order to define soil moisture and crop yield response transition functions. In the second stage, a non-linear programming model developed in GAMS defines the profit maximising land allocation between crops at the beginning of the season and the optimal scheduling of irrigation between these crops. Constraints in the model are the soil moisture transition and yield response transition functions, upper and lower boundary conditions on soil moisture

[5] The distribution of profits between farmers may change however.

(field capacity and wilting point), crop rotations, water supply, land area and non-negativity. Cropland allocation and irrigation timing and volume for each crop are the decision variables in the model. The shadow value of irrigation water[6] in the optimal cropping model is endogenously defined by its marginal physical productivity, which is a function of the crops it is allocated to and its timing of application during each crop growth stage (Acharya, 1997). The conversion of simulated yields into net revenues is again accomplished with the 2005 farm budget data.

Formally, the objective function, soil moisture and yield response transition functions are defined as:

$$\max NB = \sum_{i=1}^{m} A_i (P_i * Y_i - VC_i) - FC_i \quad (1)$$

where NB = Total net benefit, A_i =planted acreage for crop *I*, P_i = the farm-gate price for crop *I*, Y_i = per acre yield for crop *I*, = VC_i : per acre variable production costs for crop *I* and FC_i : fixed production costs for crop *I*

Subject to:

Soil Moisture Transition Constraint:

$$M_{ij} = \gamma_{i0} + \gamma_{ij-1} M_{i,j-1} + \beta_{ij} I_{ij} + \nu_i \quad (2)$$

where M_{ij} = the soil moisture available for crop i beginning of week *j*, γ_{i0} = the crop specific initial soil moisture condition, γ_{ij-1} = coefficients associated with soil moisture carry over, crop i end of week *j*-1, β_{ij} = coefficients for irrigation water application, crop i start (first day) of week *j*, $= M_{i,j-1}$: soil moisture available to crop i at beginning of week *j*-1,

[6] The shadow value of a resource is the additional net profit an extra unit of that resource would provide a farmer if it was available for use.

I_{ij} = irrigation water applied to crop *i* at the start of week *j* and v_i = error term, residual between the regression model soil moisture and the MIKE SHE simulation for each crop

Yield Response Function:

$$Y_{ij} = \alpha_{i0} + \sum_{j=1}^{n} \alpha_{ij} * M_{ij} + \varepsilon_i \quad (3)$$

where Y_i = crop yield for crop *I,* α_{ij} = yield production coefficient, crop *i* end of week *j,* M_{ij} = the soil moisture available to crop *i* beginning of of week *j,* ε_i = error term, residual between the regression model yield index and the MIKE SHE simulation for each crop, *m* = total number of crops, including set-aside option and *n* = total number of weeks.

3.2.2 Modeling preferences for urban and environmental water

Piped water supplies in the provincial capital Buon Ma Thuot (BMT) have only been operational since 2002 following completion of a DANIDA funded project. In rural centers piped water systems are currently being introduced. Block tariffs were introduced in BMT at part of the DANIDA project, however insufficient variability in the tariff structure combined with the limited time-series dataset precludes the revelation of consumer surpluses based on econometrically derived price elasticity estimates. Further precluding the use of revealed preference approaches is the fact that the majority of urban and periurban households in the DLP supplement piped water with water from other sources, such as private or collective wells or water vendors. There is evidence that non-piped water is the preferred source for many household activities for socio-cultural reasons. Without data on these preferences econometric models are likely to be under-specified. Another complication results from the unreliability of the piped water service. During the 2003/2004 dry season for example, the Buon Ma Thout Water Supply Company enforced rolling planned outages in BMT due to insufficient water stocks in its reservoirs and exhaustion of approximately half of its deep wells. The presence of structural breaks between consumption volumes and explanatory variables further complicates econometric estimation.

In the case of environmental water allocations, no pricing or market exists for these services, despite the fact that it is acknowledged by residents of BMT that water is integral to functional diversity in the DLP and impacts directly on collective welfare. In particular, preliminary focus group research indicates residents of the DLP are conscious of the general benefits and reasons for maintaining environmental flows in rivers and the contribution of water towards maintaining preventing forest fires in the plateau's remnant vegetation.

Stated preference techniques for estimating the use and non-use values of urban water supply and environmental water allocations are employed in this research. Choice Modeling (CM) is employed to assess the value of urban water while the non-use values of environmental flows are explored with contingent valuation (CV). Choice Modeling is a survey-based technique that presents respondents with a series of option sets that respondents indicate their preferred alternative from. Alternatives are defined by attributes, including a payment vehicle. In its simplest form, the orthogonal[7] design of the option sets enables econometric decomposition of the value of a good or service as an additive set of independent attributes each with their own implicit price. Using the CM approach, the composite value of sets of attributes with different levels may be defined in relation to different policy options and the WTP for a discrete shift between two options defined (Bateman, et al., 2002, Hensher, et al., 2005, Louviere, et al., 2000, Train, 2003).

Contingent valuation relies on the same utility theoretic basis as CM to define the Hicksean compensating variation for a hypothetical or actual discrete shift in some exogenously defined level (quantity or quality) of a non-market good. The approach elicits respondents' willing to pay (WTP) or willingness to accept (WTA) compensation, contingent on the change occurring. Dichotomous choice CV surveys present respondents with a statement of the environmental condition, a policy option for changing (improving)

[7] An orthogonal experimental design ensures a factor can be evaluated without confounding effects on the response variable.

the environmental condition, an estimate of the new environmental condition, a discussion of how the improvement would be achieved and an option to pay a specified amount through some payment vehicle, such as a tax (in the case of WTP). Respondents are required to indicate whether they would pay or accept the stated payment amount to have the change occur. Systematic variation in the payment amount enables econometric specification of a bid function for the environmental change, and estimation of a population's aggregate WTP/WTA the change based on the survey population data (Bateman, et al., 2002, Champ, 2003).

In the present study, at-site utility from urban water supplies is measured using the CM approach and environmental condition is modeled in a separate CV study. Indirect utility in the CM urban water study is defined as a function of supply reliability, annual average pressure and a piped water quality index. Reliability is a multi-dimensional attribute defined by the months when outages occur, the average duration of each outage and the average number of outages per month. Preference heterogeneity is described in the model as part as a function of respondent socio-demographics and respondents' water use profile. The main aim of the water use profile is to measure preference heterogeneity resulting from respondents having access to differently priced alternative water sources and water shortage coping strategies (such as in-house tanks) in the case of urban and periurban water supply.

In the CV model, WTP for improved environmental flow conditions is estimated based on a single index measuring three different levels of dry season flow in the Krong Buk, Ea Tul and Ea Knir rivers (10, 20 and 30 percent increases). These rivers are the three biggest tributaries of the Srepok River, run through the survey area, and are likely to be familiar to many respondents. To our knowledge this is the first effort to model environmental flows using a stated preference technique in Viet Nam.

3.3 INTEGRATION OF BIOPHYSICAL AND ECONOMIC MODELS

The integration objective of the physical and economic models is to enable the spatially distributed analysis of systematic variation in several broad scenario categories over the short to medium term:

- Climate scenarios: assessment of impacts of changes in climatic factors due to natural variability
- Land management scenarios: assessment of impacts of different land management strategies, primarily cropland allocation and farm level irrigation practices on biophysical states and outcomes
- Price shock scenarios: analysis of impact of price changes in agricultural factor inputs and output prices on cropland and irrigation decisions.

Biophysical and economic models of human behavior are compartmentally linked, with outputs from each model manually transferred between modeling components and welfare estimates summarized in Excel. The approach does not attempt to integrate biophysical and economic sub-models into a holistic model as this approach would require that each model adopts the lowest level of spatial and temporal resolution in the other (Bockstael, et al., 1995).

Analysis of a scenario proceeds in four stages. In the first stage initial conditions are defined for the DLP for the analysis period. Second, the cropping pattern for the DLP and irrigation schedules for each crop are defined in MIKE SHE. Both cropping and irrigation schedules can be spatially distributed, for example on the basis of an expected distribution of climatic conditions. Discussed in section 3.2, the crop and irrigation schedules can be based on the profit-maximizing crop and irrigation allocation defined in the non-linear programming model or could be non-optimal scenarios defined by the user including the base case scenario. In the third stage, the MIKE SHE simulation is run, typically over a period of one year. The simulation generates several outputs that are used as inputs to assess social welfare outcomes of the simulation. These are (i) irrigation water deficits: based on supply availability and crop demand irrigation water deficits are identified for crops in each command area; (ii) time series of river discharge ($m^3\ s^{-1}$) (iii) time series of head elevation in the saturated zone.

Social welfare outcomes of the MIKE SHE simulation are evaluated in the fourth stage. To calculate agricultural productivity and profitability, irrigation deficit data is compared to the irrigation schedule to define the actual irrigation applied to the crop. Aggregation rules allow these deficits to be defined on a basis defined by the analyst, such as by crop, command area or sub-catchment. This actual irrigation schedule is then input into the crop growth simulators to define the final agricultural yield for crops in the scenario and to calculate the profitability of irrigation water for the aggregation structure. Welfare from dry season flows in Krong Buk, Ea Tul and Ea Knir rivers are evaluated directly based on simulated discharges from the MIKE model. Urban water outcomes are evaluated based on groundwater head elevations in the Ea Co Tam region, the source of urban water for BMT. Analysis of the comparative welfare from alternative scenarios is achieved through comparison of the distributed welfare impacts of the alternative scenario and the business as usual (BAU) scenario, consistent with BCA principles.

4 SOME PRELIMINARY RESULTS

4.1 INTRODUCTION AND METHOD

This section briefly reports some initial biophysical simulation results from two scenarios analyzed in the MIKE SHE model. The objective of this analysis was to determine whether changes in irrigation management on robusta plantations would result in demonstrable change in regional hydrodynamics. This is essentially a test to determine whether the calibrated hydrodynamic model is sensitive to change in the key irrigation parameters. These results do not explicitly measure the social welfare impacts of these changes, however the results are instructive towards understanding the magnitude and direction of welfare changes resulting from improved robusta irrigation management in the

DLP.

For the simulation period 1995 to 2001, four irrigation scenarios were analyzed. The first was a BAU scenario, which simulated existing irrigation practices whereas the second scenario set irrigation timing and volumes at a level demonstrated to result in maximum yield with no reduction in bean quality based on (“the Alternative”) (D'haeze, 2005, D'haeze, et al., 2003). Nested in these scenarios were “wet” and “dry” irrigation scenarios (table). Farmers in the DLP modify the number, volume and timing of irrigations depending on whether the preceding wet season has been normal or dry (D'haeze, 2005). Following a “dry” wet season for example, farmers will generally irrigate earlier and will apply more water more frequently in order to ensure fruit setting compared to a normal rainfall year.

Determination of whether the farmer adopted a “normal” or “dry” irrigation strategy in the model was based on quintile separation of fourteen years of wet season rainfall data for the DLP. For years with “normal or better” wet season rainfall the normal irrigation schedule was applied. For years where wet season rainfall was dry or worse a dry irrigation strategy was assumed. Statistical analysis revealed significant differences in the distribution of wet season rainfall to the east and west of the central dividing range of the DLP, but not within these regions. Regional differentiation between irrigation strategies was made on this basis.

Table 2: Simulated robusta irrigation schedules

	BAU		Alternative	
Irrigation date	Dry year	Normal year	Dry year	Normal year
15 Dec	990		330	
15 Jan	935	990	330	330
15 Feb	605	781	330	330
15 Mar	605	781	330	330
Total irrigation (m^3 ha^{-1})	3,135	2,552	1,320	990
Over-irrigation ratio	2.38	2.58		

4.2 RESULTS

Comparative analysis of the BAU and Alternative simulations between the 1995 to 2001 simulation demonstrate marked differences in three measures: (1) head elevation in the saturation zone; (2) dry season river discharge; and (3) irrigation deficit.

Head elevation in the saturated zone was greater in the Alternative scenario in all sub-catchments and across all years simulated. Average head elevation in the Alternative scenario was approximately 30 centimeters higher then the BAU case across all catchments. Consistent with expectations, differences were negligible during the wet season, and most pronounced towards the end of the dry season (March to April) following the intensive coffee irrigation period.

Regarding river discharge, average dry season (December to April) baseflows in the Ea Knir, Ea Tul and lower Krong Buk between 1998 and 2001 demonstrated marked increases in simulated discharge, with average dry season discharge increasing 60 percent, 22 percent and 13 percent for the Ea Knir, Ea Tul and lower Krong Bruk rivers respectively (Table 3).

Table 3: Simulated dry season discharges, Ea Knir, Ea Tul and lower Krong Buk rivers, 1998-2001

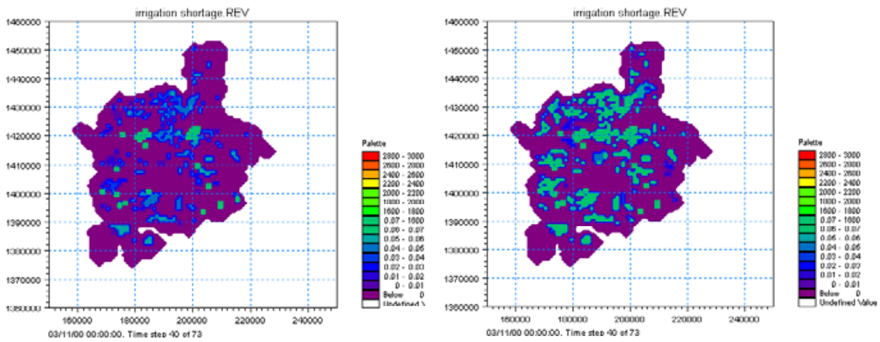
Dry season average 1998-2001	Ea Knir	Ea Tul	Krong Buk (lower)
BAU discharge ($m^3 s^{-1}$)	0.86	2.19	5.59
Alternative discharge ($m^3 s^{-1}$)	1.36	2.68	6.31
Increase in discharge ($m^3 s^{-1}$)	0.50	0.49	0.72
Percentage increase in discharge	58.1%	22.4%	12.9%

Irrigation deficits are calculated on the basis of supply shortages against crop specific demand for the irrigation command area the crop is allocated within. Command area irrigation in MIKE SHE is determined by water availability from the command area's primary irrigation source, following a set of decision rules. Command areas irrigated by surface water systems such as rivers and irrigation canals allow irrigation demand to be met when discharge rates from the surface water source exceed prescribed minimum flows.

Discharges into the irrigation command area are similarly governed by maximum discharge rates. The maximum well depth and a flow rate define irrigation constraints for groundwater extraction. When the supply system is operating within its system constraints irrigation occurs based on the crop's defined irrigation schedule. Where the system is operating outside the hydrologic constraints no irrigation occurs; irrigation deficits are defined on this basis.

Irrigation deficits for the BAU and Alternative scenarios from March 2000 are presented in Figure 1. The deficit distribution is representative of all scenario years, with only the severity of the deficit changing. Consistent with initial expectations, irrigation deficits in the BAU scenarios more prevalent and severe, with the deficit severity primarily a function of the volume and distribution of the preceding wet season's rainfall.

Figure 1: Spatial distribution of Alternative (left) and BAU (right) irrigation deficits, March 2000



4.3 SOME INTERIM CONCLUSIONS

The findings presented in this section, while general in nature, enable several conclusions to be made. First, a plateau-wide reduction in robusta irrigation from the BAU to the Alternative would appear to result in pervasive changes in the hydrodynamics of the DLP, as measured by groundwater head elevation, river discharges and related irrigation demand deficits. So long as groundwater is a binding constraint on other uses of water (seasonal agriculture / urban / environmental) these changes are welfare improving. This result indicates the importance of integrating farm level practices with system level dynamics in the evaluation of water resource policies for the DLP. Second, the calibrated MIKE model developed can be employed to assess the impacts of alternative water allocation strategies in the DLP. Third, while the model can simulate biophysical impacts of alternative water allocation strategies, it does not provide insight into the relative, distributed welfare outcomes associated with these allocations. In order to understand distributed welfare outcomes further work is required including: (1) understanding the impact of increased dry season base flows on river health, including estimation of the sustainable yield required to avoid stream, spring and water-dependent ecosystem degradation (Croke and Jakeman, 2004, D'haeze, et al., 2004) and social preferences for these states; (2) defining the impact of irrigation deficits on agricultural yield and farm-level profitability; and (3) understanding the value of more reliable urban water supplies in order to establish trade-offs with the agricultural sector.

5 CONCLUSION

Faced with increased pressure on water resources there is a need to improve water resource management in the DLP. To address these needs, an integrated approach to assessing the social welfare impacts of alternative water allocation strategies is being developed to assist decision-makers and stakeholders in identifying and assessing options for water resource management. Given the predominance of irrigated agriculture in the region, a key focus of the approach addresses the impact of agricultural land and irrigation management on regional hydrodynamics and social welfare outcomes. The framework compartmentally integrates biophysical and socioeconomic data and evaluates net welfare outcomes from both use and non-uses.

Results from the initial biophysical modeling effort have demonstrated satisfactory results, both in terms of the accuracy with which the simulation model calibrates to observation data and in terms of model sensitivity to different land management and irrigation strategies. Results presented in this paper contrast the biophysical outcomes from two simulations: a BAU and Alternative case. While the results provide some indication of the expected direction of social welfare outcomes, they cannot estimate their magnitude. Ongoing work is focused on estimating the distributed economic values causally associated with these outcomes.

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