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WATER ALLOCATION POLICIES FOR THE DONG NAI RIVER BASIN IN
VIETNAM: AN INTEGRATED PERSPECTIVE

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ABSTRACT

Recent water sector reforms, increased scarcity and vulnerability of existing water resources, combined with declining public funding available for large-scale infrastructure investment in the sector have led to an increased awareness by the Government of Vietnam for the need to analyze water resource allocation and use in an integrated fashion, at the basin scale, and from an economic efficiency perspective. This paper presents the development, application, and results from an integrated economic-hydrologic river basin model for the Dong Nai River Basin in southern Vietnam that attempts to address these issues. The model framework takes into account the sectoral structure of water users (agriculture, industry, hydropower, households, and the environment), the location of water-using regions, and the institutions for water allocation in the basin. Water benefit functions are developed for the major water uses subject to physical, system control, and policy constraints. Based on this modeling framework, policies that can affect water allocation and use at the basin level, including both basin-specific and general macroeconomic policies, are analyzed.

Keywords: River basin model, water allocation policy, integrated assessment, Vietnam, Dong Nai basin

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Water Allocation Policies for the Dong Nai River Basin in Vietnam: An Integrated Perspective

Claudia Ringler[1] and Nguyen Vu Huy[2]

1. INTRODUCTION – BACKGROUND ON THE DONG NAI RIVER BASIN

The Dong Nai River Basin (DNRB) is the largest national river basin and the economic center of the country in southern Vietnam. The basin includes lowland areas that are subject to annual flooding in the wet season and salinity intrusion in the dry season as well as mountainous highland areas of up to 1,600 m. In addition, for administrative and planning purposes, a series of several smaller coastal basins[3] are combined with the Dong Nai basin adding to a total surface area of 48,471 km^2 within Vietnam, or about 15 percent of the country's land surface area (see also Figure 1).

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[1] International Food Policy Research Institute, Washington, D.C.
[2] Sub-Institute for Water Resources Planning, HCMC, Vietnam.
[3] In the following, references to the Dong Nai basin include the surrounding coastal area, unless specified otherwise.

Figure 1--The Dong Nai river basin
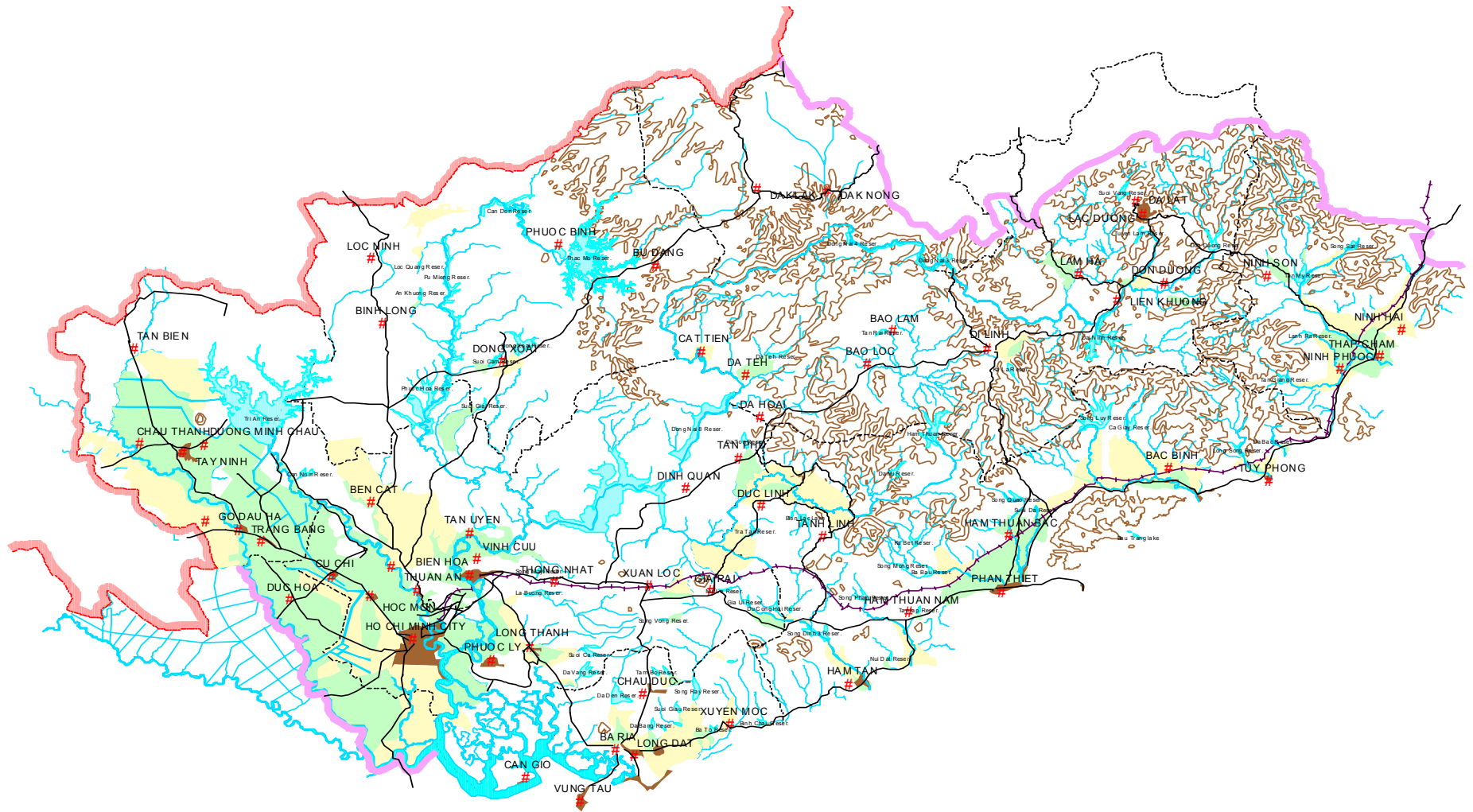
The basin includes 10 provinces and Ho Chi Minh City.[4] As can be seen in Table 1, the

DNRB is highly developed, with a relatively low share of agricultural GDP, relatively high

income per capita, and a high population density, compared with other regions in Vietnam.

Table 1--Economic indicators for the provinces in the Dong Nai River Basin

Province	Land area	Gross irrigated area	Population	GDP	Share Agriculture GDP	Share Industrial GDP	Income per capita
	2000	1999	2000	1999	1999	1999	1999
	(ha)	(ha)	('000)	(M USD)	(%)	(%)	(USD/cap)
Binh Duong	269,555	20,693	738	376	19	55	29.1
Binh Phuoc	685,598	24,844	687	114	65	8	23.6
Binh Thuan	783,809	71,231	1,066	141	47	21	19.9
Ba Ria - Vung Tau	190,000	20,762	823	3137	5	82	32.2
Dak Lak	388,909	12,097	99	433	71	8	27.7
Dong Nai	589,474	59,188	2,039	878	24	50	31.9
HCMC	209,505	69,742	5,222	5036	2	44	59.3
Long An	188,153	143,147	810	414	53	19	23.2
Lam Dong	976,440	88,245	1,038	222	60	14	29.1
Ninh Thuan	336,006	42,307	516	103	53	13	16.6
Tay Ninh	402,812	199,619	979	268	45	19	22.2
TOTAL	5,020,261	751,874	14,018	11,123	14	51	

Note: GDP and income refer to the entire province, not just basin area.
Reference: Land area: Sub-NIAPP; Gross irrigated area: adjusted from SIWRP; Population and GDP: various statistical yearbooks; Income per capita: GSO (2001).

It accounts for slightly more than half of total industrial GDP. Although, on average, the

basin population of 14 million people is relatively affluent, there are several poor districts and

provinces, including large areas in Ninh Thuan and Binh Phuoc provinces and rural districts in

Binh Thuan, Dak Lak, and Lam Dong provinces. Although the share of agriculture in total GDP

has been declining over time, the agricultural sector in the basin is highly diversified and

dynamic, with products ranging from basic staples like rice and maize to raw materials for the

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[4] About 19% of Dak Lak, 90% of Lam Dong, and 51% of Long An are included in the basin area. Unless mentioned otherwise, only basin areas of these provinces are referred to.

local industry, including cotton, rubber, and sugarcane, to high-valued crops, like coffee, fruit, grapes, pepper, tea, and vegetables.

Total discharge is estimated at 47.065 BCM (billion cubic meters), including about 6-7 BCM of Mekong flows. Rainfall averages 2,000 mm, but can be as low as 700 mm in some coastal areas. The DNRB has 5 major rivers: the Dong Nai mainstream, the Be, the Sai Gon, and the La Nga as major tributaries, and the Vam Co Dong system that joins the Dong Nai just before the outlet into the Sea. There is one major interbasin transfer to the Cai Basin in the coastal area (within the Dong Nai basin planning unit) of around 20 m^3/sec and a second transfer is under construction (Figures 1, 2).

The DNRB ranks second in hydropower potential in the country and in 2000, total installed hydropower capacity reached 1,182 MW with average annual power production of 4,881 GWh. Total investment cost of existing hydropower projects is estimated at USD 1,105 million (including Ham Thuan- Da Mi, Thac Mo, and Tri An reservoirs). In addition, the basin includes Dau Tieng, the largest irrigation reservoir in Vietnam. Several additional reservoirs are currently under construction.

On the institutional side, several reforms in the water sector have recently impacted upon or will impact on the basin in the near future. In January 1999, a new Water Resources Law went into force. According to the Law, the Ministry of Agriculture and Rural Development (MARD)[5] is in charge of overall management of the country's water resources, but the Government may delegate authority for specific water uses to other ministries; water allocation is carried out from a river basin perspective adhering to the principles of fairness and reasonability; priority in use is

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[5] In November of 2002, following the establishment of the new Ministry of Natural Resources and Environment (MONRE), MONRE was assigned responsibility for state management of water resources as well as other natural resources and environment, whereas public water services delivery is to be carried out by MARD and other ministries with water-related responsibilities.

accorded to drinking water in both quality and quantity (Article 20); and both water use and wastewater discharge are to be licensed by provincial government authorities (People's Committees) under the guidance of MARD. In April of 2001, MARD established a basin Planning Management Council for the DNRB. Detailed operation rules are not yet finalized, but it is assumed that in a first phase, the Council will focus on river basin planning.

The following sections introduce the modeling framework; describe model data and validation; and present a baseline and an optimization scenario. Based on this modeling framework the consequences of changes in crop prices and irrigation efficiency, increased trade liberalization, and the establishment of water use rights and alternative trading regimes on the basin economy are analyzed.

2. MODELING FRAMEWORK

In order to support coordination of management in the Dong Nai River Basin, and to assist the recently established Dong Nai River Basin Planning Management Council a better understanding of water supply, demand, and its value in various uses is needed. Moreover, an understanding of the role of alternative policy instruments in alleviating likely future water shortages in the basin is necessary to allocate scarce resources across irrigation, hydropower development, and urban water supply demands. The complexities involved in water allocation and use in the Dong Nai River Basin—and any river basin in the world—require a holistic approach to the planning and management of its water resources to achieve an optimal utilization that is at the same time sustainable, efficient, and equitable (McKinney et al. 1999, Rogers and Fiering 1986).

The two principal approaches to river basin modeling are simulation—to simulate water resources behavior based on a set of rules governing water allocation and infrastructure operation; and optimization—to optimize allocation based on an objective function and accompanying constraints. Although simulation and optimization models have differing objectives, they are in fact complementary tools to address problems related to the competition over scarce water resources and the design and assessment of alternative systems of water allocation.

The model developed for the DNRB draws on previous economic-hydrologic modeling carried out at IFPRI, in particular, for the Maipo River Basin in Chile (Rosegrant et al. 2000). It belongs to the class of integrated economic-hydrologic river basin models and includes hydrologic, economic, and institutional components. The model focus is on the economic component. The river basin model is developed as a node-link network, which is an abstracted representation of the spatial relationships between the physical entities in the river basin. Nodes represent river reaches, reservoirs, and demand sites, and links represent the connections between these entities (Figure 2).

Figure 2--Dong Nai River Basin Network
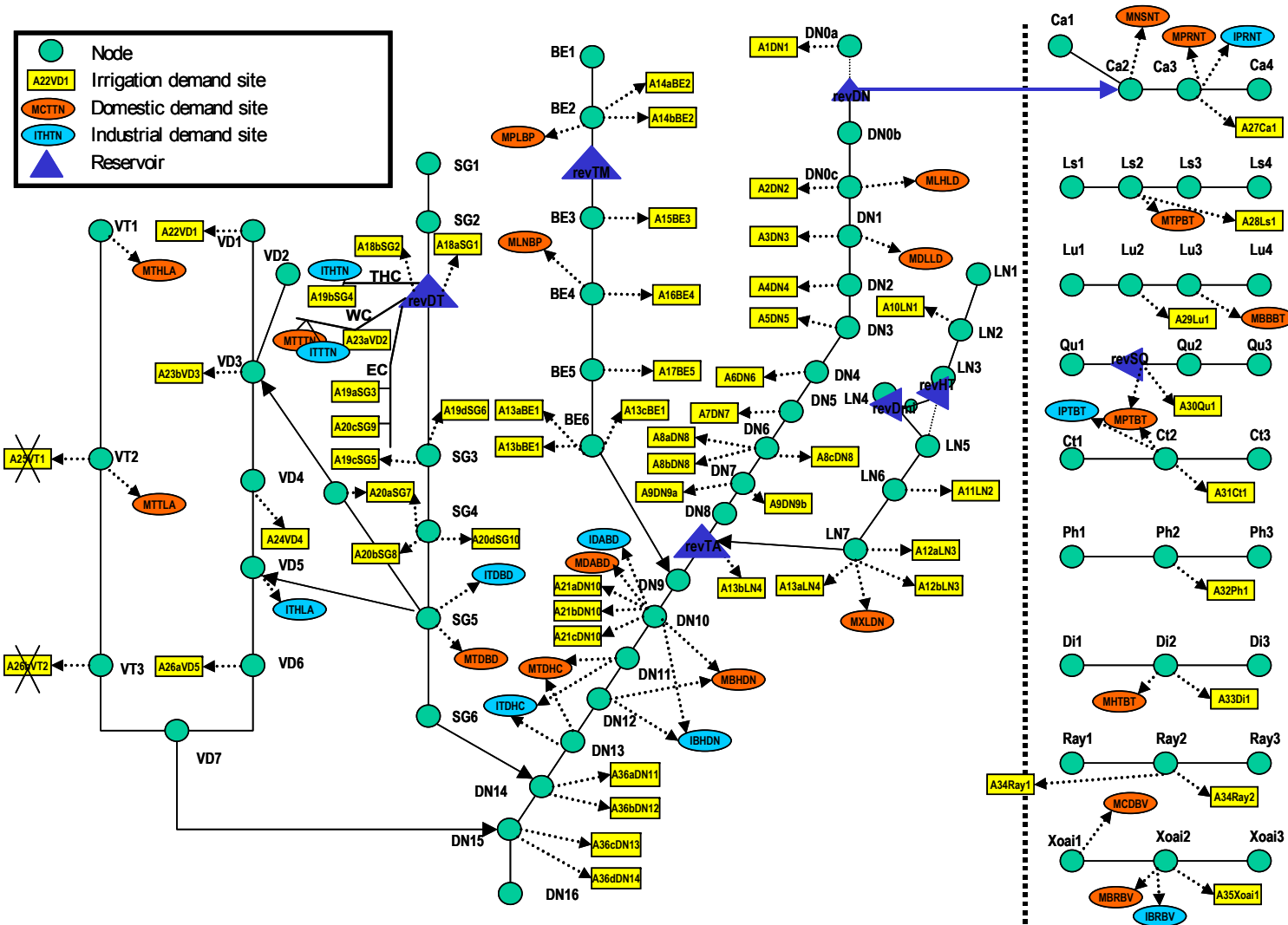
Inflows to these nodes include water flows from the headwaters of the river basin, as well as local rainfall drainage. Flow balances are calculated for each node at each time period, and flow transport is calculated based on the spatial linkages in the river basin network.

For modeling purposes, provinces are considered the major modeling units in the river basin model. Agricultural demand sites are delineated according to 37 sub-catchments and administrative boundaries, resulting in 60 irrigation demand sites.[6] For domestic demand sites, adjacent districts have been summed up, yielding 48 domestic demand sites. For industrial water use, 12 demand sites are delineated for the provinces with major industrial water use: Ba Ria-Vung Tau, Binh Duong, HCMC, Dong Nai, as well as several provinces with lower industrial development: Binh Thuan, Long An, Ninh Thuan, and Tay Ninh. The model also incorporates the major existing reservoirs for hydropower production, irrigation, and flood control.

Thematically, the modeling framework includes three components: (1) hydrologic components, including the water balance in reservoirs, river reaches, and crop fields; (2) economic components, including the calculation of benefits from water uses by sector, demand site, and country; and (3) institutional rules and economic incentives that impact upon the hydrologic and economic components. Water supply is determined through the hydrologic water balance in the river system; while water demand is determined endogenously within the model based on functional relationships between water and productive uses in irrigated agriculture, domestic and industrial uses, and hydropower. Water supply and demand are balanced based on the objective of maximizing economic benefits to water use. Environmental requirements to control saltwater intrusion are included as flow constraints. The time horizon of the model is one

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[6] Two irrigation demand sites on the West Vam Co River have not been included as they are outside the Dong Nai basin planning unit.

year with 12 periods (months). The following section describes the hydrologic and economic components in more detail.

HYDROLOGIC COMPONENT

Hydrologic relations and processes are based on the flow network. They include: (1) flow transport and balance from river outlets/reservoirs to crop fields, and domestic and industrial demand sites; (2) return flows from irrigated areas and urban-industrial areas; (3) reservoir releases; (4) instream water uses; and (5) groundwater.

The basic flow balance at a node in the basin network is calculated as:

$$flow\_downstream = flow\_upstream + local\_drainage +$$
$$return\_flows - withdrawals - (evaporation)\ losses \qquad (1)$$

The rainfall-runoff process is not included in the model. It is assumed that runoff starts from rivers and reservoirs. Effective rainfall for crop production is calculated outside of the model, and included into the model as a constant parameter. As groundwater data was scarce, the exploitation capacity of shallow groundwater was included, and withdrawal estimates as available, but groundwater was not modeled separately.

ECONOMIC COMPONENT

The objective of the model is to maximize the annual net profits from water uses in irrigation, households and industries, and hydropower generation. The objective function is formulated as:

$$Max \quad Obj = \sum_{a} VA_a + \sum_{m} VM_m + \sum_{in} VI_{in} + \sum_{pw} VP_{pw} \qquad (2)$$

where:

VA	net profit from irrigated agriculture
VM	net benefit from municipal water use
VI	net profit from industrial production
VP	net profit from power production
a, m	
in, pw	indexes for irrigation, domestic, industrial demand sites and power station

Crop Yield Function

In order to establish a relationship between inputs other than water and crop yield, a

quadratic production function is chosen (see Eq. 3) due to its properties of decreasing marginal

returns to additional inputs and substitutability of inputs.

The quadratic function is expressed as follows:

$$
yst_{a,c} = [\alpha_1, \alpha_2, \alpha_3, \alpha_n,] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_i \end{bmatrix} + [x_1 \quad x_2 \quad x_3 \quad x_n] \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{1m} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{2m} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{3m} \\ \gamma_{n1} & \gamma_{n2} & \gamma_{n3} & \gamma_{nm} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_i \end{bmatrix} \tag{3}
$$

where α and γ are the input coefficients, and *x* are inputs by crop *c*. Water inputs in this

equation are fixed at the yield-maximizing level. In order to establish a relationship between crop

yield and water stress, the crop yield-water stress relationship described in Doorenbos and

Kassam (1979) and Doorenbos and Pruitt (1977) is used.

$$
y = yst * (1 - ky) * (1 - ET_A / ETM_M) \tag{4}
$$

where:

y	actual yield (water-stressed) (mt/ha)
yst	non-water stressed yield (mt/ha), from the quadratic production function
ET_A	seasonal actual evapotranspiration (mm)
ET_M	seasonal potential evapotranspiration (mm)

The net profit function for irrigated agriculture is formulated as:

$$VA_a = A_{a,c} * y_{a,c} * pc_c - (lc_c + mc_c + fc_c + pec_c)$$
$$- W_{a,c} * pw_c$$

(5)

where:

A	area harvested (ha)
W	irrigation water applied (m^3)
y	actual yield from FAO relationship, (mt/ha)
pc	crop price at farm gate (USD/mt)
lc	labor cost (family and hired) (MD/ha)
mc	machinery/animal cost (USD/ha)
fc	fertilizer cost (USD/ha)
pec	pesticide cost (USD/ha)
pw	water fee (USD/m^3)

Domestic Net Benefit Function

The net benefit function for domestic water uses (*VM*) is derived from an inverse demand function for water. In a first step, a double-log function is estimated.

$$\ln(mwd) = \psi + \beta \cdot \ln(I) - \varepsilon \cdot \ln(P_{mwd})$$

(6)

where:

mwd	per capita water demand (m^3/cap)
Ψ	constant
I	income (US\$/cap/month)
P_{mwd}	price paid for water (US\$/m^3)
ε	price elasticity of demand
β	income elasticity of demand

The inverse of the demand function is then integrated over the space of $mwd_0{}^7$ - W to estimate the consumer surplus:

$$CS = VM_m = \sum_{urban,rural,pd,pop} \frac{e^{\left(\psi/\varepsilon\right)} \cdot I^{\left(\beta/\varepsilon\right)}}{\left(1 - 1/\varepsilon\right)} \cdot \left\{ mwd_m^{\left(1-1/\varepsilon\right)} - mwd_m^{0\ \left(1-1/\varepsilon\right)} \right\}$$
$$- mwd_m * P_{mwd}$$

---

[7] There are no clear guidelines for choosing mwd_0. Here it is defined as a share of actual per capita consumption. Thus, consumer surplus here can only be accrued for consumption levels above average demand. It is not considered crucial in this modeling framework, as allocation is driven based on marginal benefits.

where:

CS	Consumer Surplus (US$ million)
mwd^0	per capita normal water demand (m³/cap)
P_{mwd}	price for water, includes urban and rural water and surface and groundwater
e	EXP
urban, pd	
rural, pop	indexes for urban/rural parameters, for time period (*pd*) and population (*pop*)

Industrial Net Profit Function

A production function approach to industrial water demand, which is conceptually correct given that water is an input to a marketed end product, cannot be realized due to the lack of industrial survey data. Therefore, a synthetic willingness-to-pay curve is developed based on the observed level of water use, and average, and marginal water use. Based on a literature review, a price elasticity of water demand of 0.71 is chosen (equal to three times the average price elasticity for connected and non-connected households in HCMC used in the household water demand function). Second, the mean contribution of water to production cost was assumed to be 0.05. Based on these data points, the following function can be estimated:

$$\ln(iwd) = \mu - \theta \cdot \ln(P_{iwd})$$

(8)

where:

iwd	industrial water withdrawal (m³/month) *[available]*
μ	constant
θ	price elasticity of industrial water demand *[synthesized]*
P_{iwd}	industrial water price (US$/m³) *[available]*

Based on the known values of iwd, P_{iwd}, and the estimated θ, the constant can be calculated. Equation 9 presents the net benefit function to increased water use.

$$VI_{in} = \sum_{in,pd} \frac{e^{\left(\mu/\theta\right)}}{\left(1 - 1/\theta\right)} * \left\{ iwd^{\left(1 - 1/\theta\right)} - iwd^{0\left(1 - 1/\theta\right)} \right\} - iwd * P_{iwd}$$

(9)

where:

iwd	industrial water withdrawals (m³/month)
iwd⁰	industrial withdrawals at normal demand (m³/month)
e	EXP

Hydropower Net Profit Function

To estimate power production, in a first step, power production efficiency is calculated based on daily release and power production data. Profit from power production *(VP)* is calculated as a linear function, multiplying power production *(pow)* with the difference between power selling price *(pp)* and power production cost *(pc)* for each hydropower station.

$$VP_{pw} = Pow_{pw} \cdot (pp_{pw} - pc_{pw}) \qquad (10)$$

3. MODEL DATA AND VALIDATION

The model is calibrated to 1999/2000 data. In the following, data sources for the model are briefly described and a run with fixed water allocation (BAS) is compared with selected observed data.

Hydrologic Data

Source flow was determined by the hydrology division of SIWRP (Sub-Institute for Water Resources Planning, Ho Chi Minh City) based on a rainfall-runoff model called RRMOD for 1978-1998 for a total of 37 river nodes/reaches. Together with the withdrawal nodes, a total of 82 nodes are included in the model. Total estimated basin discharge amounts to 47.1 BCM. As these data are *ex-post* depletion, estimated actual depletion, just under 4 BCM, is added to these observed natural flows. From the model runs, total discharge in the baseline simulation (BAS)

amounts to 47.5 BCM. Figure 3 shows that reservoir releases (average for 1994-1998) at Tri An,

the largest hydropower reservoir in the basin, compare well with model discharge.

Figure 3--Dong Nai mainstream flow from model compared with average Tri An reservoir release (1994-1998)
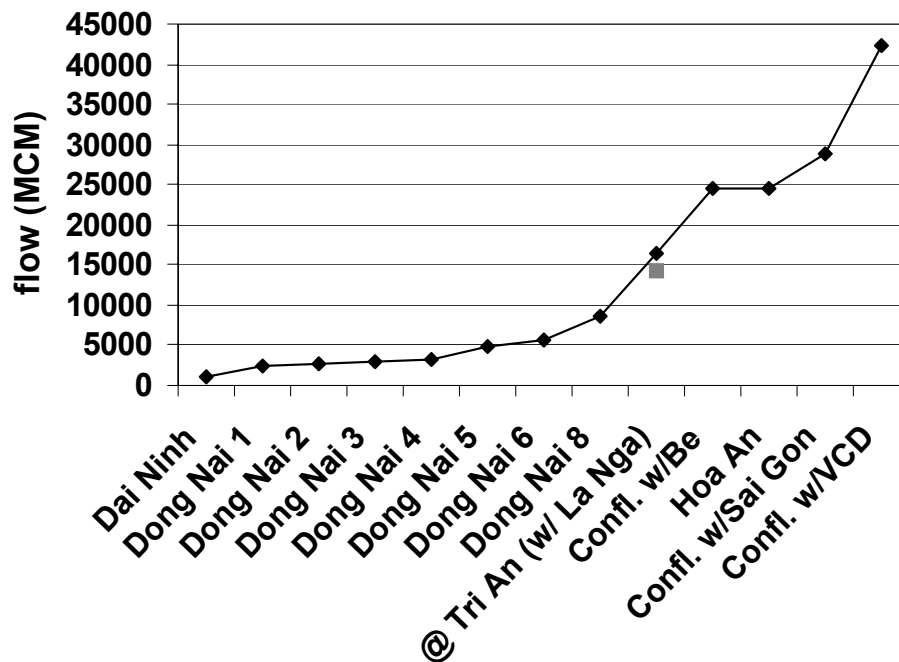
A minimum instream flow requirement for all river reaches in the basin of 10 percent of

source flow has been included to guarantee basic river habitat. In addition, estimates for

minimum flow requirements to control saltwater intrusion and secure safe drinking water supply

for the lower basin, chiefly HCMC, have been included. They are 85 m^3/sec for the Dong Nai

River at Binh An water supply plant and 25 m^3/sec on the Sai Gon at the location of the future

Ben Than water supply plant.

AGRICULTURAL DATA

The parameters for the crop yield function were collected by Sub-NIAPP (Sub-National

Institute for Agricultural Planning and Projections) in an extensive farm household survey

covering 700 households in the 11 provinces of the DNRB. The survey covers the Summer-

Autumn season of 1999 to the Winter-Spring season of 2000 (SubNIAPP 2001). Based on the survey data crop yield functions were estimated for the major irrigated annual (bean, maize, peanut, rice, sugarcane, tobacco, vegetables) and perennial crops (coffee, fruit tree, other tree, pepper) in the basin. Annual crops are separated by season (Winter-Spring, Summer-Autumn, and Rainy Season). Moreover, paddy and vegetable crops are further subdivided by region (coastal area, mountainous area, and lowland area). The input variables incorporated are in USD/ha: labor, machinery, fertilizer, pesticides, and water. Family labor is valued at the prevailing wage rate stipulated by the farm households. Water includes both estimated irrigation water applied and effective rainfall (calculated based on daily rainfall observations prevailing over the survey period). Mean values of major input variables by crop, which are used in the model, are shown in Table 2.

Table 2--Yield function parameters, area-weighted mean values by crop

	Price	Yield	Labor	Machinery	Fert N	Fert P	Fert K	Pesti-cide	Irr-Water	ER
	(USD/mt)	*(mt/ha)*	*(MD/ha)*	*(USD/ha)*	*(kg/ha)*	*(kg/ha)*	*(kg/ha)*	*(USD/ha)*	*(mm)*	*(mm)*
beanDX	484	1	44	46	32	47	20	14	255	28
coffee	641	3	331	10	314	227	96	74	1352	879
frtree	310	8	308	6	227	147	61	71	1182	728
maizeDX	132	6	68	47	82	89	29	24	403	78
maizeHT	101	6	82	43	61	61	25	18	352	292
otree	366	33	841	5	963	1025	413	871	1401	403
peanDX	315	3	99	41	77	101	46	60	363	77
peanHT	329	1	84	40	48	63	22	28	372	293
pepper	3392	3	540	20	325	325	138	159	960	597
riceDXc	107	5	93	36	117	68	22	27	830	82
riceDXm	120	5	80	44	100	58	21	20	768	146
riceDXu	111	4	62	34	91	71	26	31	782	181
riceHTc	111	5	92	35	108	66	24	32	895	397
riceHTm	113	4	73	46	100	67	18	24	746	573
riceHTu	104	4	63	33	100	64	28	37	853	430
riceMUAc	112	4	82	33	97	57	17	28	808	412
riceMUAm	113	4	81	53	126	53	24	14	773	525
riceMUAu	108	4	58	27	96	56	16	28	737	436
sugarc	16	50	140	19	172	131	53	31	1541	608
tobDX	1299	3	411	32	273	200	94	45	402	105
vegiDXc	182	19	308	26	241	204	69	100	309	50
vegiDXm	83	27	243	42	211	228	61	87	250	107
vegiDXu	134	12	160	46	220	155	21	57	295	114
vegiHTc	199	19	335	19	272	214	69	106	333	113
vegiHTm	144	22	251	36	232	320	62	188	269	190
vegiHTu	122	11	129	52	185	144	20	54	356	253
vegiMUAc	171	24	385	14	266	194	56	107	257	179
vegiMUAu	119	14	169	33	222	170	27	56	328	223

Note: DX = Winter-Spring season; HT = Summer-Autumn season; MUA = Rainy season.
*Note: Due to a lack of observations for beanHT and beanMUA, the respective values from vegiHTu and vegiMUAu were taken.

Irrigation service fees (ISF) in Vietnam for public systems are decided at the province level following government guidelines. ISF are area-based and can vary by crop, season, and type of irrigation water supply (gravity or pump irrigation). Currently, ISF only partially reflect the scarcity value of water; fees are typically higher for pump irrigation, but also typically lower for rice, which consumes relatively more water. Survey results indicate average basin ISF of

USD 19/ha, USD 12/ha and USD 5/ha for dry-season, summer-autumn season, and rainy season paddy, compared to USD 92/ha for perennial coffee plants that are pump-irrigated. ISF per ha were converted to volumetric values for modeling purposes.

There are no consistent databases for irrigated area and irrigation sources in Vietnam. Sub-NIAPP estimates gross irrigated area for 1999/2000 of 819,136 ha, whereas SIWRP estimates an area of 781,349 ha. Irrigated areas for upland crops are not separated in statistics on irrigation. For this analysis, they were distributed according to statistical yearbooks on total area and survey results. It was assumed that only perennial crops are irrigated with groundwater. Estimated yield function and production costs are applied to the gross irrigated area for 1999 of 759,480 ha.

DOMESTIC WATER USE DATA

Domestic water delivery data was collected from the various water supply companies in the basin. Water loss rates in the basin range from 19 percent for Ba Ria-Vung Tau (BRVT) province to 49 percent in Trang Bang, Tay Ninh province. Water tariffs from public supply companies were included as available. About half of the companies apply progressive block tariffs. Average rates vary from VND 1,600/m^3 (USD 0.11/m^3) for Long An province to VND 2,529/m^3 (USD 0.18/m^3) in Da Lat City, Lam Dong province. For individual pumping and most rural domestic water uses, a supply cost of USD 0.1/m^3 was assumed. Public water supply companies serve only about 60 percent of the population of major cities, and people with household connections consume, on average, substantially more than non-connected households. For those districts and areas without public supply, a minimum supply standard of 40-50 l/cap/day was assumed. This results in total domestic water supply of about 920,500 m^3/day and per capita supply of 64 l/day.

The parameters for the domestic benefit function were estimated separately for connected and non-connected households based on the 1995 household water demand behavior survey carried out by GKW/SAFEGE (GKW/SAFEGE 1996). The survey was carried out in the 12 inner and four peripheral districts of HCMC. The price and income elasticities estimated were then applied to other districts in the basin, following adjustments for rural-urban shares (to which non-connected and connected parameters were applied, respectively), rural-urban incomes, and rural-urban consumption shares.

INDUSTRIAL WATER USE DATA

Industrial water use estimates for the Dong Nai basin have ranged from 130-2,500 MCM (million cubic meters) per year (Ngoc Anh 2000 and Boggs 1995, respectively). For this study, industrial water use was collected from the industrial zones of the four major industrial provinces in the basin (BRVT, Binh Duong, HCMC, and Dong Nai). However, water supply data for these zones was sparse. Moreover, substantial industrial production takes places outside of designated industrial zones. Industrial water supply data was also collected from municipal water supply companies in the various provinces in the basin. As these data were still not sufficient, industrial water use was estimated based on the water use coefficients for industrial products presented in Boggs (1995, see Boggs' Table 6).

In 1999, total net industrial water demand was estimated at 287 MCM, 44 percent of which was delivered from surface water sources, the remainder from private or industrial zone managed wells. The water tariff that public water companies charge to industries varies little among provinces and is usually a flat rate. Among the provinces with available data, the rate is

lowest in Long An at VND 2,600/m^3 (USD 0.19/m^3) and highest in Binh Thuan at VND 4,500/m^3 (USD 0.32/m^3).

HYDROPOWER DATA

Power production parameters in the model include efficiency estimates computed from historic daily reservoir release data, operation rules, dead and maximum storage, maximum turbine flow, and area-storage and elevation-storage relationships. Figure 4 presents the operation curve for Tri An, together with historic storage values and model outcomes. The graph shows that reservoir operation curves in place are not adhered to religiously in the basin. Figure 5, which compares power production from model results and historic data for Da Nhim reservoir, shows that the model replicates current production levels well. Hydropower production costs, supplied by PECC2, for the major stations, range from USD 0.012/kWh for Thac Mo to USD 0.033/kWh for Ham Thuan and Da Mi stations; and electricity selling prices range from USD 0.038/kWh for Tri An to USD 0.07/kWh for Da Nhim station. For analysis purposes, it is assumed that hydropower profits accrue to those provinces where the reservoir is located.

Figure 4--Operation curve, baseline and historic storage, Tri An Reservoir
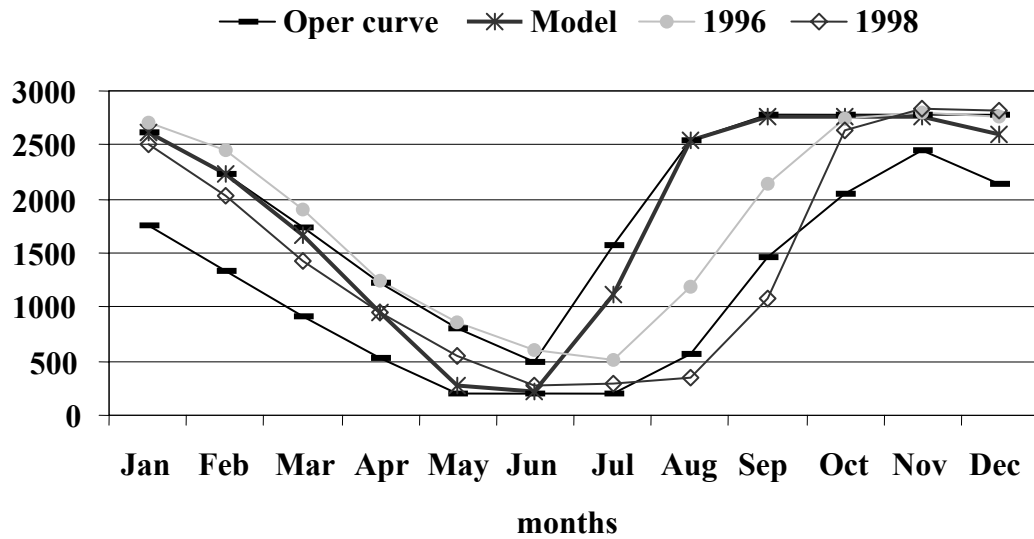
Figure 5--Hydropower production, Da Nhim Station, historic data and baseline result
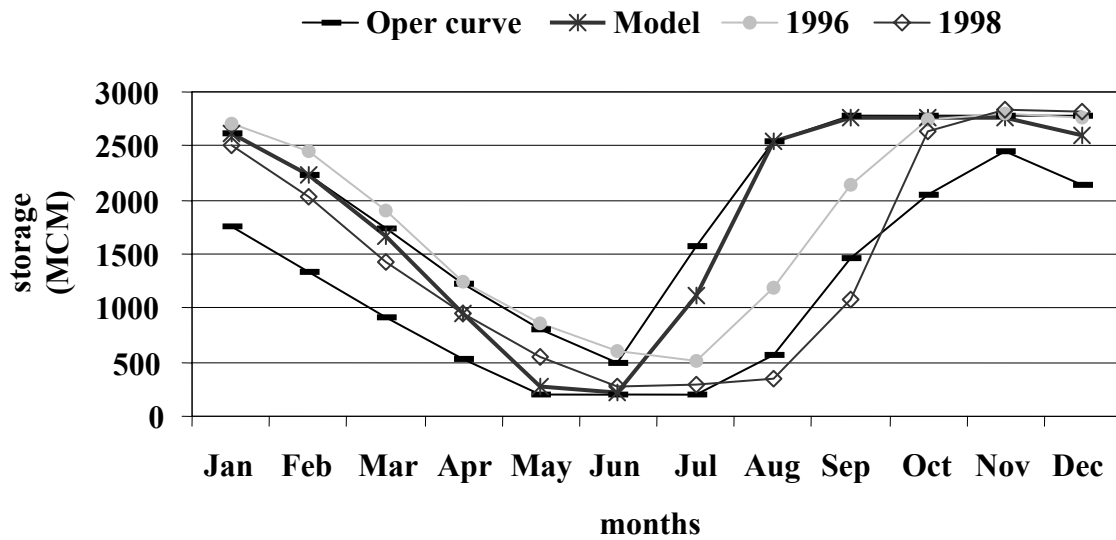
The model has been coded in the GAMS modeling language, a high-level modeling system for mathematical programming problems. It consists of 50,317 single equations (rows) and 117,691 single variables (columns) with 185,034 non-zero coefficients. The CONOPT3 solver for highly nonlinear problems has been used to solve the model.

4. BASELINE (BAS) AND OPTIMIZATION (OPT) RESULTS

BAS attempts to recreate the water allocation and use situation prevailing in 1999/2000. This can usually not be achieved through full optimization, because optimized allocation is based on a partial incorporation of the reality into the modeling framework, and because the logic of the modeling approach assumes economic efficiency as the main driving force for water allocation across time and space, with perfect in- and foresight into the scarcity value of water in its various uses. For BAS, water allocations to various sectors are fixed. In the irrigation sector, crop yield and crop production inputs, including labor, fertilizer, and water are fixed at average levels, for example. Moreover, irrigated crop area allocation levels are fixed. Power is produced within operating rules.

Full optimization (OPT) presumes an omniscient decision-maker, which can be represented, for example, through the Dong Nai River Basin Organization. However, transaction costs for full optimization of basin resources in the real world would be tremendous. For OPT, irrigated area ranges from 0.2-1.5 of observed irrigated area, and crop inputs other than water are within a range from 0.8-1.2 of average input levels. Domestic demand is within a range of 0.7-1.15 of observed demand, and industrial demand within a range of 0.5-1.5 of actual demand. Reservoir releases operate within operation rules.

Under BAS, total off-stream water withdrawals from surface sources are estimated at 6,157 MCM, 12 percent of total runoff. Minimum flow requirements for drinking water on the Dong Nai and Sai Gon Rivers account for a further 3,469 MCM. Surface withdrawal shares are 89 percent for irrigation, 5 percent for domestic uses, and 5 percent for industrial water uses. In addition, total groundwater abstractions amount to 705 MCM or 6.9 percent of total shallow groundwater capacity. About 292 MCM are pumped for irrigation, 163 MCM for domestic uses, and 251 MCM for industrial uses. Total power production amounts to 5,287 GWh. Under the OPT scenario, water can be allocated more freely across sectors, following optimization objectives, within the bounds specified above, and the physical and system control constraints and minimum instream and downstream flow requirements. Under this scenario, surface water withdrawals increase to 6,353 MCM; and groundwater pumping increases by 4 percent. Compared to BAS, gross irrigated area under OPT drops by 75,000 ha. The decline is largest for rice crops, but coffee area declines as well. Area under upland crops, on the other hand, increases by 55,000 ha (see also Figure 6). Increases are particularly large for peanut in the dry season and vegetables in the rainy season.

Figure 6-- Changes in crop pattern, BAS and OPT scenarios
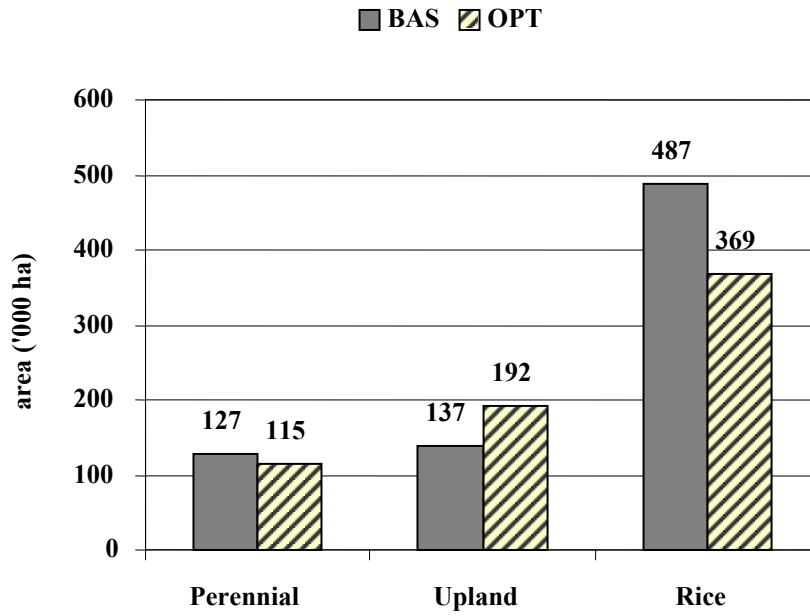
Figure 7 presents the distribution of natural flows, model discharge, and water demands (including instream flow demands for drinking water in HCMC) across the year for the BAS scenario. A few observations can be made based on this graph.

Figure 7--Distribution of flows and demands, BAS scenario
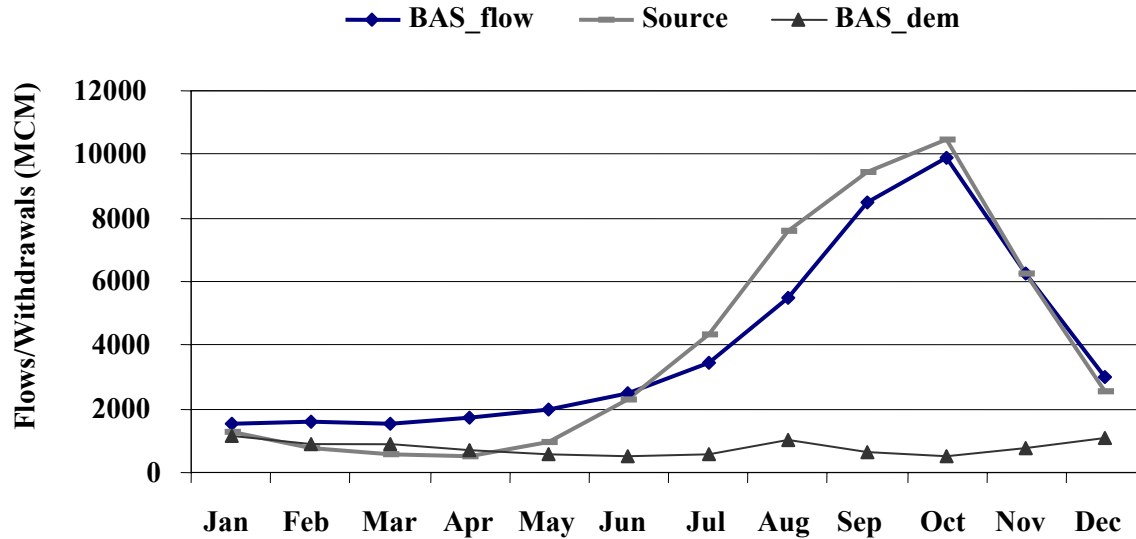
First, it shows clearly the large variation in flow between the dry and rainy seasons, ever

after construction of three major reservoirs in the basin. Second, the graph shows that the

construction of these reservoirs has been vital to prevent water shortages in the dry season, as

demands surpass natural (prior to storage) flows during February to April, by between 164 MCM

and 339 MCM. Overall, the DNRB can be characterized as an 'open' river basin based on this

graph, as excess water is available, over and above all committed legal, ecological and

environmental requirements, even during the dry season. However, the basin will likely soon

approach a 'semi-closed' state, where sufficient water resources are available during the rainy

season, but off-stream and instream water needs compete with each other during the dry season.

In so-called 'closed' basins, finally, there is no excess water flowing out of the basin; all water

resources are committed to use (Keller, Sakthivadivel, and Seckler 2000). The latter state is

unlikely to occur in the Dong Nai basin due to the large wet season flows and storage potential.

Table 3 presents net profit per hectare and the productivity of irrigation water for irrigated basin crops under BAS and OPT.

Table 3--Net profit per hectare and productivity of irrigation water by crop, BAS and OPT

	Profit per ha		Profit per m³	
	BAS	OPT	BAS	OPT
	(US$/ha)		*(US$/m³)*	
otree	9074	9238	0.43	0.44
pepper	5654	6027	1.40	1.09
tobDX	3463	3578	0.39	0.40
vegiHTc	2380	2629	0.29	0.32
vegiMUAc	2248	2595	0.58	0.67
vegiDXc	2205	2455	0.36	0.41
vegiHTm	2181	2475	0.48	0.55
vegiMUAm	1406	1429	1.20	1.22
vegiDXm	1175	1275	0.26	0.28
vegiDXu	1131	1211	0.25	0.28
frtree	1069	1879	0.12	0.21
vegiHTu	870	911	0.29	0.31
beanHT	844	886	0.17	0.18
beanMUA	801	856	0.33	0.36
vegiMUAu	800	855	0.31	0.33
peanDX	574	588	0.07	0.07
maizeDX	438	470	0.05	0.05
coffee	358	505	0.06	0.06
maizeHT	311	323	0.15	0.16
peanHT	261	276	0.12	0.13
riceHTm	164	128	0.03	0.04
beanDX	152	232	0.03	0.03
riceMUAu	129	182	0.02	0.02
riceDXu	126	205	0.01	0.01
riceHTc	85	227	0.01	0.01
sugarc	81	278	0.01	0.02
riceDXc	80	222	0.01	0.01
riceMUAc	77	194	0.01	0.02
riceMUAm	53	122	0.02	0.03
riceHTu	39	147	0.01	0.02

DX = Winter-Spring, HT = Summer-Autumn, MUA = Rainy Season; c = coastal area (BRVT, Binh Thuan, and Ninh Thuan; m = mountainous area (Binh Phuoc, Dak Lak, and Lam Dong provinces); u = lower basin (Binh Duong, Dong Nai, HCMC, Long An, and Tay Ninh).

Net profits per hectare are largest for the category 'other tree' (including grapes and mulberry trees) and pepper, followed by tobacco and some of the vegetable crops. Profits per ha are lowest for sugarcane and some of the paddy crops. At the lower end, there is significant

variation between the BAS and OPT scenarios, as the flexible adjustment of inputs other than water under OPT helps avoid some of the low crop profits in the BAS scenario.

The productivity of irrigation water, defined as USD/m^3, depends on both the profitability of the crop and its need for irrigation water, which again is determined by growing season, growing length, and climatic factors. Baseline results indicate that water productivity is high for vegetables planted in the highland areas and the summer-autumn season. This is because these crops consume very little irrigation water. Among the non-vegetable crops, pepper, 'other tree' and tobacco stand out as crops with relatively high profit per unit of water consumed. Unsurprisingly, water productivity is lowest for sugarcane and various paddy crops.

5. ALTERNATIVE SCENARIOS

SENSITIVITY ANALYSIS

Sensitivity analyses are carried out to test the robustness of baseline results. Parameters tested include changes in the climatic situation—inflows and effectively usable rainfall—changes in the efficiency with which water resources are being used at the field and at the level of primary and secondary canals. The final sensitivity analysis refers to changes in selected agricultural commodity prices. Results are presented in Table 4.

Table 4--Sensitivity analysis, various parameters (comparison with opt, percentage values)

Parameter	Levels/ Values	Irrigation Profit	Domestic Benefit	Industrial Profit	HP Profit	Total Profit	Total Ag Withdrawals	Irrigation Pumping	Total Dom. Withdraw-als	Domestic Pumping	Total Ind. Withdrawals	Industrial Pumping
Low flow (%)	0.6	90.2	100.0	100.0	71.9	94.4	100.0	66.3	100.0	100.0	100.0	100.0
	0.5	87.7	100.0	100.0	62.8	92.8	99.5	64.5	100.0	100.0	100.0	100.0
Field-application Efficiency[a]	0.5	87.5	100.0	100.0	100.1	96.6	100.0	69.0	100.0	100.0	100.0	100.0
	0.9	110.5	100.0	100.0	99.9	102.8	100.0	104.6	100.0	100.0	100.0	100.0
Conveyance and Distribution Efficiency[b]	0.60	105.4	100.0	100.0	99.9	101.5	100.0	71.2	100.0	100.0	100.0	100.0
	0.75	112.4	100.0	100.0	99.8	103.3	99.5	63.9	100.0	100.0	100.0	100.0
	0.375	92.2	100.0	100.0	100.1	97.9	100.0	106.7	100.0	100.0	100.0	100.0
Coffee/Pepper Price Changes	1998	130.5	100.0	100.0	99.9	108.3	100.0	106.0	100.0	100.0	100.0	100.0
	2001	82.4	100.0	100.0	100.8	95.3	97.3	23.8	100.0	100.0	100.0	100.0

Note: Runs are based on OPT.
Notes: /a Base efficiency is 0.7; b/ Base efficiency for combined conveyance and distribution efficiency is 0.5.

Hydrologic Year

During a dry-year case, represented by 60 percent and 50 percent of average inflows and effective rainfall, respectively, farm incomes from irrigated agriculture drop to 90 percent and 88 percent of OPT levels, respectively. Profits from hydropower production decline similarly, to 72 percent and 63 percent, respectively, as less flows are available to keep the turbines operating. Under both dry-case scenarios, groundwater pumping for irrigation drops significantly, to 66 percent and 65 percent of OPT levels, respectively, due to the increase in domestic and industrial pumping—which dominate over irrigation pumping—to compensate for reduced surface water availability. Domestic and industrial water use benefits are not affected due to their high marginal return to water usage.

Irrigation Efficiency

One important means to reduce water losses is the improvement of on-farm field efficiency. In the baseline scenario, field application efficiency is estimated at 0.7, that is, 70 percent of the water applied at the field level is used beneficially by plants. If the field application efficiency level were increased to 0.9 (and thus overall efficiency to 45 percent), for example, through investments in irrigation technology in the entire basin, then irrigation profits would increase to 111 percent of OPT levels (an increase of USD 42 million), and hydropower profits would decline by a very small amount (a reduction of USD 0.1 million). Increased on-farm efficiency would make low-profit crops relatively more feasible, and both irrigated area and groundwater pumping would increase. The annual cost of increased on-farm efficiency, not incorporated here, should not surpass the estimated increase in net benefits from irrigation estimated for this alternative.

When field application efficiency is reduced to 0.5, however, that is only half of the water arriving at the field can be used effectively for crop evapotranspiration (and thus overall efficiency is reduced to 25 percent down from 35 percent), then irrigation profits drop to 88 percent of OPT levels. The relatively more expensive groundwater pumping would decline to 69 percent of OPT levels. This decline would be compensated by increased surface water withdrawals.

The Government of Vietnam is currently undertaking a large investment project to line irrigation canals to reduce water losses. The total investment plan over the 1999-2005 period amounts to USD 758 million for all of Vietnam. The investment funds have several sources. Most of the funds will be allocated from MARD and based on Decision No. 66. However, a substantial share will also be sourced from ISF and the land tax, and the reminder from the farmers themselves. At USD 52 million, the canal lining investments planned and ongoing in the Dong Nai Basin are relatively small compared to the overall investment schedule (7 percent of the total), but are still substantial. Irrigation management companies hope to increase conveyance and distribution efficiency following canal lining from 0.7 to 0.9 (IMC Ninh Thuan and IMC Cu Chi, personal communication); these estimates (including the original levels) appear somewhat optimistic. In the baseline, conveyance and distribution efficiency combined are estimated at 0.5.

If the ongoing canal lining would increase the conveyance and distribution efficiency across the basin to a level of 0.75 (translating into an overall efficiency level of 0.53), then profits from irrigation would increase to 112 percent of OPT levels (or an increase by USD 50 million), at the same time that irrigation withdrawals would decline. Groundwater pumping for irrigation purposes would decline dramatically, to 64 percent of OPT levels—a reduction by 95 MCM—as cheaper surface water would become more abundant, whereas surface withdrawals would increase by 65 MCM. Increased irrigation surface withdrawals, in turn, would lead to a slight

reduction in profits from hydropower production (USD 0.3 million annually). Thus, at this increase in efficiency, the canal lining investment appears to be a viable option, compared to costs incurred.

If the ongoing canal lining activities would increase the combined conveyance and distribution efficiency levels to a value of 0.6 only (translating into an overall efficiency level of 0.42), then the additional respective annual profits would be only USD 22 million. In this case, total irrigation withdrawals would not decline, with a reduction of irrigation pumping of 76 MCM completely offset by an increase in surface withdrawals (Table 4). Thus, no water savings would be achieved at the basin level.

If, on the other hand, maintenance on primary and secondary canals is deferred—as is currently happening in many Vietnamese irrigation systems—the combined conveyance and distribution efficiency might decline to a level of 0.38 based on an increase in canal losses of 25 percent (and translating into an overall efficiency level of 26 percent). In this case, irrigation profits would drop to 92 percent of OPT levels (a drop by USD 31 million). The resulting decline in surface irrigation water withdrawals (18 MCM) would be compensated by an increase in groundwater pumping to 107 percent of OPT levels and total basin profits would decline to 98 percent of OPT values (decline by USD 31 million). Thus, even if the canal-lining project would not be implemented, it is clear that deferring maintenance on public irrigation systems will cause long-term costs to the irrigation sector in the Dong Nai Basin and Vietnam.

Finally, the outcomes for irrigation profits are larger for changes in on-farm field efficiency as they apply to both surface and groundwater irrigation sources.

Commodity Price Changes

Several major agricultural commodities experienced sharp declines in Vietnam and elsewhere over the past few years. Although the rice price in Vietnam has dropped significantly

in the Mekong Delta over this period, prices in the DNRB remained stable due to the relatively lower quantity and higher quality of rice produced. To evaluate the impact of recent price changes on farmer incomes, alternative simulations are carried out for the 1998 and 2001 coffee and pepper prices, which are major cash crops affected by the price decline. Converted to US dollars, the prices implemented in the model are for coffee: USD 1,033/mt, USD 641/mt, and USD 372/mt, for 1998, survey year (1999/2000), and 2001, respectively—a drop by a factor of 2.7 over three years—and for pepper: USD 4,590/mt, USD 3,392/mt, and USD 1,149/mt, a drop by a factor of 4 over the period. The results of the alternative simulations are shown in Figure 8.

If the 1998 coffee and pepper prices would prevail, irrigation profits would increase to 131 percent over OPT values, and total basin profits to 108 percent. For the case of 2001 coffee and pepper prices, profits from irrigated agriculture drop to 82 percent of OPT values, and total profits decline to 95 percent of OPT values. In the latter case, total irrigation withdrawals decline slightly. Moreover, agricultural pumping, which is a major water source for pepper and coffee crops, drops sharply, to 24 percent of OPT levels, while profits from hydropower production slightly increase (see Figure 8).

Figure 8--Sensitivity analysis – Impacts of changes in coffee and pepper prices
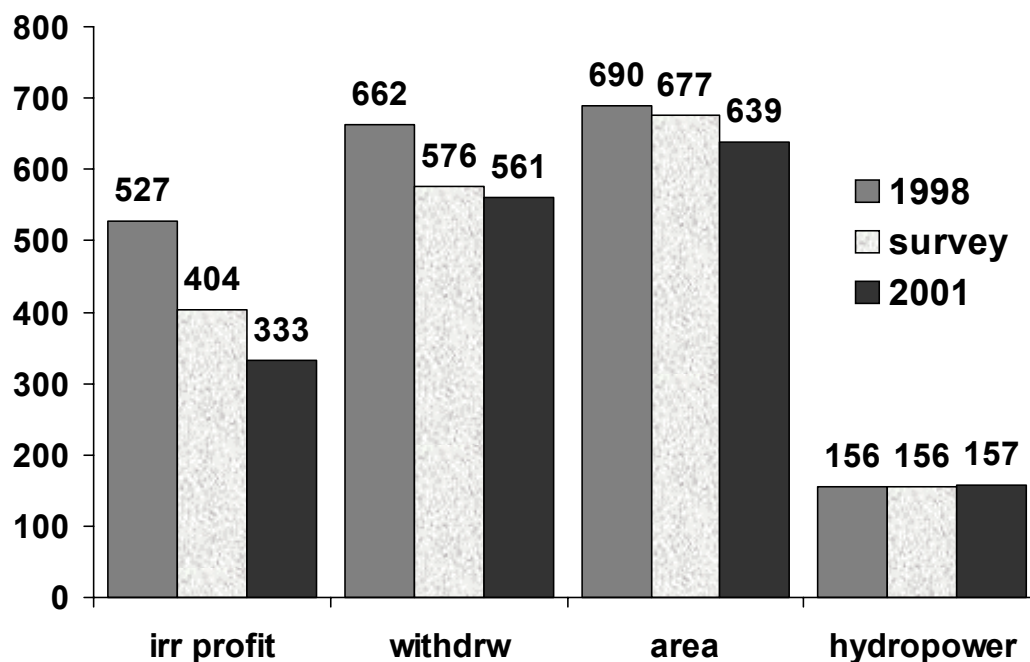
POLICY ANALYSIS—WATER USE RIGHTS (WRI), BROKERAGE MECHANISM (BRK), AND MARKET CLEARING (MC) SCENARIOS

The Vietnam Water Law of 1999 calls for a permit system that applies to both surface and groundwater. Use rights for groundwater are granted for a period of 15 years and for surface water for a period of 20 years. The permit system only applies to large-scale users. Small quantities—chiefly for household uses and small-scale uses in agriculture, forestry, aquaculture, and other home enterprises—are not included in the permit system. In times of water shortages, domestic uses get priority over irrigation, industrial, hydropower, and environmental uses. At the absence of the implementation of these regulations, allocation is currently controlled implicitly through the investment decision-making process. Public agencies and companies, through public investments in new water-using facilities, determine *de facto* the basic allocation of surface water among users. Such uses include irrigation schemes, hydropower stations, ports, and municipal

water supply systems. Moreover, in the absence of enforced water use rights, the construction of new infrastructure implicitly reallocates water among the various sectors, without compensating potential historic users of this water.

Experience in several developed and developing countries has shown that as economies develop, and more infrastructure is being built, water is typically reallocated from the agriculture sector to the rapidly growing urban and industrial sectors (Rosegrant and Ringler 1998). This process can threaten the livelihoods of irrigating farmers and associated rural economies. The establishment of water use rights (WRI), as envisioned in the Vietnam Water Law, and as recently detailed in decisions passed by the Government, could empower water users in all sectors, as it establishes both rights and responsibilities to specified water use. If water shifts to other, typically urban and industrial sectors, irrigators and other users would need to be compensated. However, this requires that representatives of irrigating farmers, like Water User Associations, farmer cooperatives, or Irrigation and Drainage Management companies are allocated use rights, as farmers are exempted/excluded in the current legislation. Moreover, establishing water rights can serve as an incentive to invest in productive water uses, as there is some security to be able to use the water for a prolonged period. Furthermore, water use rights provide incentives for all sectors to invest in water-saving technologies, as water outside of the existing water use right would have to be obtained at a certain cost, and—in well-developed water use right systems—water can be traded, that is, purchased and sold, among sectors.

The establishment of water use rights together with the possibility to sell unused use rights to an agency or to purchase additional use rights, if the water can be used productively, can help poorer farmers to obtain additional income. The implications of this type of system—which

can be implemented in the form of a brokerage mechanism (BRK)—on water allocation, use, and farmer incomes, and overall basin profits will be examined in the following.

In practice, there have been both positive and somewhat less successful experiences regarding the implementation of brokerage mechanisms (also called clearinghouses or charge/subsidy systems). These systems have so far typically been employed to control air and water pollution. Wang and Chen (1999) present a positive outcome of the application of a charge/subsidy system in China to control industrial pollution. In particular, this system provided the Chinese industries with incentives to decrease pollution levels. Another case study in France has shown that too much bureaucracy can undermine the effectiveness of charge/subsidy systems (Glachant 1999).

If (water) economies are more advanced, a Market Clearing (MC) mechanism can be introduced that ensures that the volume of water being sold by all users equals the volume being purchased by other users within the same sector or across sectors across specified time periods, here months. The implementation of market clearing mechanisms requires more sophisticated communication and information systems compared to the introduction of a water brokerage system.

The establishment of water use rights is a highly complex task and requires the determination of many aspects to ensure its workability. For example, in the case of Vietnam, the allocation of water use rights to groups of farmers (Water User Associations) or Irrigation and Drainage Management Companies (IMCs) requires the determination of initial allocation rules.

Possibilities for initial allocation include:

- designed capacity of extraction works
- actual capacity of extraction works
- historical water use pattern

- estimated water needs (WRCS 2000).

Each type of initial rights allocation will have significant consequences for the equity, efficiency, and viability and sustainability of the water rights system. The water use right scenarios implemented here envision a system where water users are registered in some form with a basin agency or authority or similar; and that the registered use confers both rights to use the amount registered as well as the responsibility to use this water in an efficient manner. Moreover, an alternative scenario envisions the future purchase and sale of these water use rights, to allow water to move into higher-valued uses without compromising the incomes of irrigating farmers.

For WRI, water rights are established for all demand sites reflecting historic usage under BAS. For the BRK scenario, in addition to the water use rights, a brokerage mechanism is implemented. All off-stream sectors can sell water up to their water use right allotment to a brokerage agency or clearinghouse (which could be the river basin agency), which compensates the users at a fixed water price, and then can relocate the resource to other sectors that might want to purchase sources in addition to their own water rights. Sales and purchases are implemented on a monthly basis. Thus, a demand site can buy in the dry season and sell during the wet season, for example. If the water sold to the agency is not allocated to other off-stream sectors, it enhances instream flows. The water price at which the agency buys and sells—the agency water price—is fixed exogenously and is the same for all sectors (under full water market conditions, the water price at which various water users at different locations in the system are willing to sell or buy water can be revealed through the shadow price). Two alternative agency prices are set at USD $0.02/m^3$ and at USD $0.06/m^3$. A third set of scenarios includes a market clearing mechanism (MC) in addition to the brokerage mechanism. That is, water use rights that are sold

or bought to an agency need to be equal in volume. Thus, the agency costs are limited to

transaction costs. Costs for the establishment and management (transaction costs) of a brokerage

and market mechanism are difficult to estimate. For the purpose here it is assumed that the

brokerage incurs transaction costs of USD $0.01/m^3$ purchased/sold and the market clearing

mechanism faces costs of USD $0.03/m^3$ traded among sectors. Net water trade equals zero. As

the model optimizes over the entire basin, a provision is included for the BRK and MC scenarios

that no individual demand site can be worse off than under the WRI case. The alternative

scenarios are implemented based on the OPT scenario, that is, they include variation in area,

yield, and crop inputs, and are based on the BAS for initial water use right allocation.

Table 5 presents selected results for the water use right scenarios with the alternatives of

brokerage mechanism (BRK) and brokerage plus market clearing (MC).

Table 5--Selected results from water trading analysis, WRI, BRK and MC scenarios

	WRI	*BRK 0.02*	BRK 0.06	MC 0.02	MC 0.06
Agency-fixed trading price (USD/m^3)		0.02	0.06	0.02	0.06
Irrigation Profit (M USD)	401	486	387	435	434
Domestic Benefit (M USD)	687	1,057	1,057	1,057	1,057
Industrial Benefit (M USD)	155	162	160	161	161
Hydropower Profit (M USD)	155	153	154	154	154
Total Profit (M USD)	1,397	1,858	1,757	1,806	1,805
Total water withdrawals (MCM)	6,309	9,670	3,923	6,326	6,334
Irrigation withdrawals (MCM)	5,615	8,719	3,054	5,411	5,430
Irrigated area (in '000 ha)	678	904	497	685	693
Government income/(cost) (M USD)		33.8	-74.6	0.0	0.0
Farmer sells (buys) (M USD)		-27.4	89.1	5.7	16.5
Dom. Sector sells (buys) (M USD)		-4.3	-12.4	-4.2	-12.6
Industry sells (buys) (M USD)		-2.1	-2.1	-1.5	-3.9
Quantity of water traded (MCM)		1,690	1,485	284	275
Average farm income per ha (USD/ha)	591	538	779	635	627
Average irrigation water per ha (m^3/ha)	8,279	9,646	6,147	7,898	7,836

Note: See also Figure 9.

When a brokerage mechanism (BRK) system is introduced, water withdrawals increase significantly compared to the fixed rights system, even though water users have to pay for additional water. The agency-fixed sale/purchase price is crucial for the determination of the agency net income or loss. In the case of a price of USD 0.02/m^3 all sectors are net buyers and a total of 1,690 MCM are purchased under BRK, for example. Thus, the agency has a net income USD 34 million from water sales for the river basin as a whole. At the same time, gross irrigation withdrawals increase to 8.7 BCM. All sectors with established water use rights gain from the clearinghouse mechanism. However, the benefits to instream uses, like hydropower, and environmental uses, decline as they do not have water use rights accorded based on the Water Law and reflected in the river basin model. Moreover, although total profits in the irrigation sector increase, these profits are spread over a much wider irrigation area, and more water-

intensive crops are brought into production. As a result, profits decline on a per hectare basis, compared to the system with fixed water rights (from USD 591/ha to USD 538/ha).

If the water price in the BRK system is set at a higher level, here USD 0.06/m^3, it is more profitable for many irrigation systems to sell part of their water use right to the water agency instead of continuing to use the full share of allocated use rights. All in all, the water agency purchases 1.2 BCM worth of water at a net cost of USD 74.6 million. This is due to the fact that the volume of water sold by farmers at this higher water price is far larger than the volume of additional water demanded by the domestic and industrial sectors (see also Table 5 and Figure 9).

Figure 9--Water use right scenarios: water sales/purchases and agency income/cost (environment)
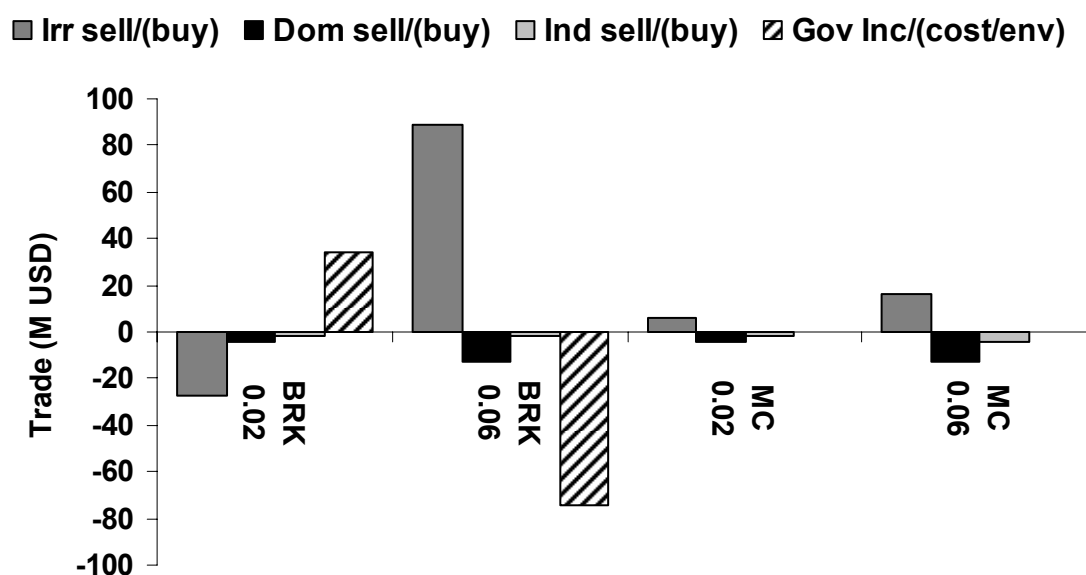
Due to the large sales of water from irrigated agriculture, the volume of gross agricultural water withdrawals declines to 3.1 BCM and irrigated area drops to 0.497 million hectares. As a result, profits from irrigated agriculture alone under the higher water price of USD 0.06/m^3 are lower compared to the irrigation profits at the agency set price of USD 0.02/m^3. However, the

important result is that under the higher water price, profit from irrigated agriculture on a per hectare basis is significantly higher compared to the WRI scenario and compared to the BRK scenario at the lower agency-set price (USD 779/ha, versus USD 591/ha and USD 538/ha). At the price offered for the water use right, irrigating farmers make a substantial share of their use rights available to other off-stream users (or the environment), while investing their remaining water resources into those crops that are more profitable per cubic meter of water ("crop per drop"). Thus, water moves to higher-valued uses, without income losses to the irrigation sector. Gross water trade reaches a level of 1.485 BCM.

If in addition to the brokerage mechanism, a market clearing mechanism is introduced, that is, net sales of water use rights across all sectors need to equal net purchases of water use rights across all sectors. In that case, the brokerage agency does not incur gains and losses apart from transaction costs. As a balance has to be reached between the water use rights available intended for sale and the demand for additional water use rights, the volume of purchases and sales drops compared to the BRK scenarios. Whereas the quantity of water traded was 1,690 MCM under BRK 0.02 (that is at the agency set price of USD 0.02/m^3) and 1,485 MCM under BRK 0.06 the corresponding volumes under the market clearing mechanism drop to 284 MCM under MC 0.02 and 275 MCM under MC 0.06, respectively. Moreover, under all MC scenarios, on average, irrigated areas, which have generally lower profits "per drop" of water compared to usage in industry and households, are net sellers of waters, whereas the latter are net buyers of the resource (Figure 9). At the higher agency price, the trade in water use rights under MC increases substantially in monetary but not volume terms, with irrigation demand site incomes from water sales increasing from USD 5.7 million to USD 16.5 million. Although net farm income per ha does not reach the BRK levels—where the agency supports water sales from irrigated areas even

if no one purchases this water—net profits per hectare irrigated are still larger compared to the

WRI case.

Figure 10 presents the outcomes of the alternative water use right scenarios for the items

of profit and water withdrawals per ha irrigated. As the graph shows, irrigation withdrawals on a

per hectare basis are largest when water in addition to the initial water use rights can be

purchased at a low price and without purchase limits.

Figure 10--Water use right scenarios: Profit and withdrawals per hectare from irrigation
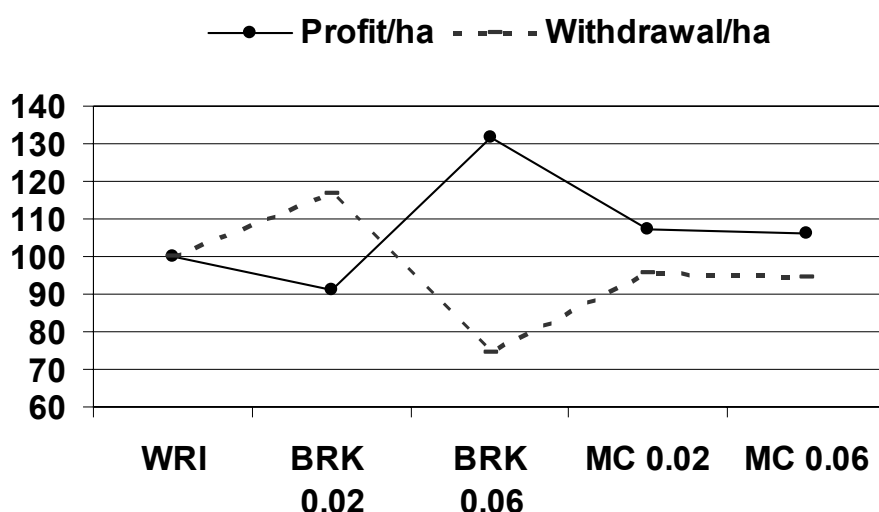
Irrigation profits on a per ha basis are largest under the BRK scenario at the higher

agency-fixed price, as in this case farmers tend to sell water in low-value rice irrigation to more

profitable uses, while maintaining irrigated areas for higher-valued crops, where the profit per

cubic meter of water applied is typically higher as well. Under the MC scenarios, purchases and

sales of water follow market-clearing rules. At the lower water price of USD $0.02/m^3$, irrigation

demand sites are unable to purchase water as domestic and industrial sectors themselves strive to

purchase water from lower-value irrigation. At the higher water price, trade is even more limited,

as domestic and industrial sectors purchase less water than the irrigation sector might be willing

to free up at this price. However, profit per ha under the MC scenarios is still higher and

irrigation withdrawals per ha are still lower compared to the WRI scenario; thus the combined objective of improved farmer incomes and water savings can be achieved under both alternative scenarios, the brokerage mechanism and market clearing.

Figure 11 presents the income of farmers from irrigation activities and from sale of water use rights.

Figure 11-- Water use right scenarios: Total irrigation and other profits
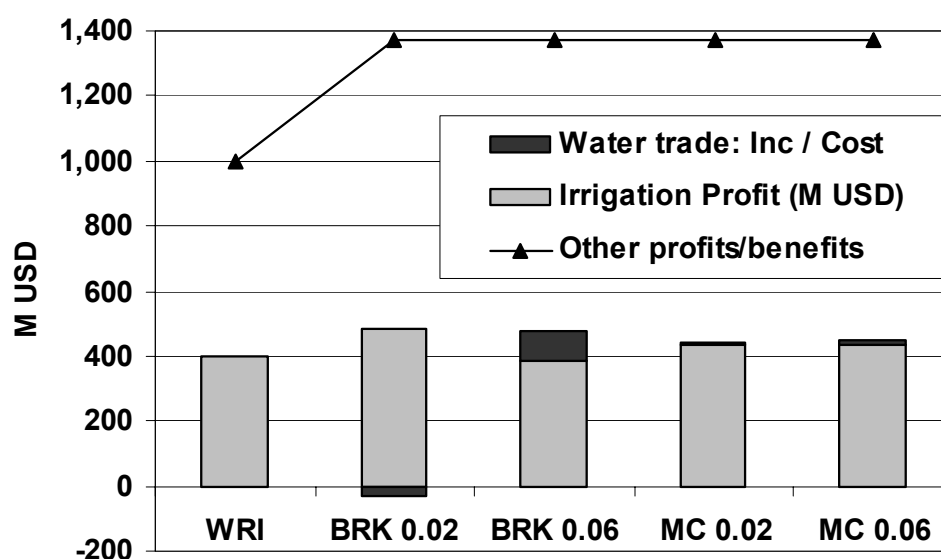
At the lower water price, USD $0.02/m^3$, irrigation demand sites are net purchasers of water under the BRK scenario, spending a total of USD 27.4 million on additional water use rights, 5.6 percent of total irrigation profits, 20 percent of total surface irrigation withdrawals, and 19 percent of total irrigation withdrawals. Under the higher water price, irrigating farmers are net sellers of water, obtaining a total of 23 percent of total irrigation profits from water sales, and selling 33 percent of total irrigation withdrawals (or 3 percent of total basin discharge). Under the MC scenario, where irrigation sites are net sellers at both specified water prices, incomes from water sales are USD 5.7 million (1.3 percent of total irrigation profits) and USD 16.5

million (3.8 percent of total irrigation profits) under the water prices of USD 0.02/m^3 and USD 0.06/m^3, respectively. Under market-clearing conditions, water sales out of agriculture reach 5 percent of total surface withdrawals under both alternative agency-set water prices.

As the Dong Nai basin economy develops and water becomes scarcer, the agency price could be increased to reflect the increasing value of water in the basin, thus prompting additional water sales and investments in water-saving technologies in irrigated agriculture as well as in the purchasing water-use sectors.

OPEN ECONOMY, INTERNATIONAL LINKAGES– TRDLIB

During the last decade or so, Vietnam has become a major or even the largest player in some international agricultural commodity markets, including pepper, coffee, and rice. Moreover, Vietnam has recently joined ASEAN and considers participation in the WTO. Increased participation in international agricultural commodity markets and increased openness to trade has led to the removal of most distortionary export taxes and import quotas that have been in place in the past, but it has also exposed local producers to the price fluctuations prevalent in some of these international markets, particularly rice.

The Open Economy and International Linkages Scenario, TRDLIB, assumes a continuation of these trends culminating in the full removal of primary economic distortions (taxes, subsidies) that affect agricultural production (and hence agricultural water use). The Dong Nai basin economy, centered on irrigated crop production, is linked to global conditions via internationally established prices of inputs (fertilizers, energy, for example) and outputs (agricultural commodities). Farmers face producer prices set in international markets and mediated by costs of inland transportation, storage and marketing margins. The scenario does not take into account secondary effects of increased trade liberalization, like a reduction in the

marketing margins, which will likely occur as the powers accorded to few traders are gradually relaxed during the increased opening to international markets and the larger introduction of competitiveness in markets. Moreover, the large remaining industrial protection levels (for example in the sugarcane industry) are not examined under this scenario.

As a study by Barker et al. (2002) shows, overall subsidy and taxation levels in the agriculture sector have declined substantially over the last two decades. In 1999/2000, estimated average net protection rates reached –7 percent for rice, -7.5 percent for coffee, -13 percent for pepper, + 7.5 percent for tobacco, +112 percent for sugarcane (1998-1999 average, industrial protection), and +16.5 for urea. The case of urea is particularly significant. Urea protection rates vary across time, but have been significant and geared at protecting the local fertilizer industry. Based on the IFPRI-SubNIAPP farm household survey, farmers paid between USD 381-1500 per metric ton of nitrogen equivalent fertilizer.[8] As the CIF border price of urea was USD 105 per metric ton in 1999, and the estimated wholesale price about USD 157 per metric ton in 1999/2000, farmers, on average, were taxed heavily for fertilizer inputs. Distortions are lower for other fertilizers, like potash and potassium, because they are mostly imported. If remaining trade barriers would be removed, domestic prices received by farmers would increase for rice, coffee, pepper, and decline for tobacco. Urea fertilizer costs to farmers would decline significantly (Barker et al., 2002). The case of sugarcane is different. Here it is the industry that is heavily protected.[9]

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[8] The average elemental nitrogen cost of rice farmers ranged from USD 382-616 per metric ton. Urea has a concentration of about 45 percent of elemental nitrogen. Thus, farmers paid about USD 171-684 per metric ton of urea.

[9] A study by CIE (2001) showed that liberalization of sugar imports would increase the real income of Vietnam by some USD 82 million each year, and sugarcane production would decline. As the profit per ha for sugarcane is already quite low, no further changes were made to the sugarcane price received by farmers resulting from the removal of the protection for the sugarcane industry.

The objectives of the TRDLIB scenario are to analyze the outcomes for cropping patterns, water allocation, and farm incomes of the removal of primary remaining distortions in agricultural input and output markets. In order to implement the trade liberalization scenario, the protection/taxation levels were removed for the irrigated crops in the basin model, that is, rice prices were increased by 7 percent, coffee prices by 7.5 percent, and pepper prices by 13 percent; and tobacco prices were reduced by 7.5 percent, and urea prices by 16.5 percent. This scenario was analyzed based on the 2010 projected Business-As-Usual (BAU) scenario with flexible area allocation.

The removal of remaining taxes on fertilizer (urea), rice, coffee, and pepper will lead to direct annual farm income increases of USD 89 million. As a result, total annual profits increase from USD 4,676 million under BAU to USD 4,765 million under the alternative TRDLIB scenario (2010 projections). Lam Dong province experiences the largest yearly benefits, at USD 25 million, followed by Binh Phuoc, at USD 13 million, and Binh Thuan, at USD 10 million. Figure 12 shows the changes in profitability per hectare for the three major crop types. Profit per ha increases most for rice crops, by 22 percent (from USD 182/ha to USD 223/ha), followed by perennial crops, by 13 percent (from USD 1,465/ha to USD 1,658/ha), and upland crops by 0.4 percent (from USD 1,048/ha to USD 1,053/ha).

Figure 12--Profit per hectare by crop type, TRDLIB and BAU scenarios
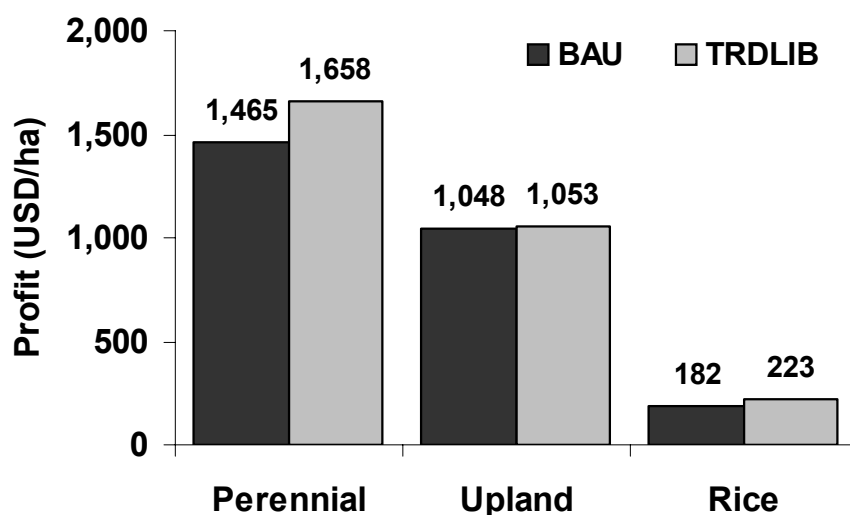
The large increase in profitability of rice crops is due to the combination of larger received output prices and reduced fertilizer input costs. This applies similarly to the large increase in profitability observed for perennial crops. Here the share of fertilizer in total production cost is the reason for the large increase in profitability. Nitrogen equivalent fertilizer, for example, averages 343 kg/ha and year for perennial crops as compared to 119 kg/ha for paddy and 125 kg/ha for upland crops. However, urea plays an important part for all crop types, and the removal of urea protection is equivalent to a direct net transfer of income to irrigating farmers.

Total irrigated area increases slightly between these two scenarios, from 1.546 million ha under BAU in 2010, with flexible area allocation to 1.548 million ha under TRDLIB, and TRDLIB helps move some of the unprofitable rice area back into the positive profit margin area. Moreover, under the TRDLIB scenario, the N-fertilizer application increases from an average of 168 kg/ha for irrigated crops in the basin in BAU to 179 kg/ha, and the P-fertilizer application increases from 126 kg/ha to 129 kg/ha; whereas K-fertilizers barely change.

6. CONCLUSIONS

The paper introduced an economic-hydrologic river basin model and its application to the Dong Nai River Basin in southern Vietnam. The model describes the water supply situation along the river system and the water demands by the various water-using sectors. Water benefit functions are developed for productive water uses and minimum instream flows are included as constraints. Water supply and demand are then balanced based on the economic objective of maximizing net benefits to water use. This structure allows for intersectoral and multi-province analyses of water allocation and use with the objective to determine tradeoffs and complementarities in water usage and strategies for the efficient allocation of water resources.

This type of model can help the provinces in the newly formed Dong Nai Planning Management Council to structure the complex reality of the Dong Nai water resources system. The model can be used both as a planning tool, focusing on the investment side, and even more so as a tool to develop strategies for basin management. The model can support policymakers in their decision-making processes from an economic efficiency perspective. Water allocation mechanisms need to be efficient, equitable, and environmentally sustainable. The model developed for the DNRB inherently ensures efficient water allocation in the basin as water is allocated according to its scarcity value to the highest valued uses and, once those are satisfied, to other uses, so long as the overall economic profit from water use across the basin increases. Finally, the model allows to analyze the impact of policies on outcomes for water and farm incomes at various levels: from changes in farmer behavior and decisions at the local/crop area level, to basin-level changes in water allocation mechanisms, up to national-level changes in macroeconomic input and output price policies.

Sensitivity analyses for changes in the overall irrigation efficiency have shown that water savings could be large. However, the appropriate means to achieve these savings—either through structural/infrastructure measures, as chosen by the government, or through nonstructural measures, like improvement in management, or the implementation of a brokerage mechanism (see below)—warrant further analysis and discussion. Only high levels of actual efficiency increase—for example, an increase in the combined conveyance and distribution efficiency to 0.75—would actually lead to sufficient increased benefits through water savings to make the USD 52 million investment currently implemented a viable one. However, other benefits, including cost savings due to reduced O&M from canal lining also would need to be considered. On the other hand, cessation of joint farmer canal cleaning can be a stumbling block for irrigation management transfer and farmer management of irrigation systems, and thus might not be conducive to the ongoing, albeit slow, process of decentralization in Vietnam's irrigation sector.

The simulation of alternative output prices received for pepper and coffee has demonstrated their large impact on the total basin economy over the last few years. The reduction in coffee and pepper prices between 1998 and 2001 alone, has led to a decline in net farm incomes by USD 194 million in the DNRB (accompanied by a large drop in groundwater pumping of 218 MCM). The drop in coffee and pepper prices is particularly worrisome, as these perennial crops are long-term investment decisions that cannot be changed in the matter of a season or even a year. The multi-year reduction in coffee prices in Vietnam, in fact, has led to the destruction of several thousand hectares of coffee plants—albeit mostly older and less productive ones—and has led to the substitution of some area planted to the *robusta* variety with the more highly priced *arabica* variety. However, coffee prices have since recovered to closer to 1998 levels, returning the crop back to profitability. The decline in pepper prices was not large enough to wipe out area. Stabilizing and increasing farmgate prices through improved quality

and other measures must be a key goal for Vietnam's agricultural policy, particularly for perennial crops, which cannot quickly adjust to the large price swings experienced in the basin in recent years.

Results from the water use rights scenarios have shown that appropriate incentives can shift irrigated area allocation towards water savings while farmer incomes are maintained and urban and industrial water use shares increase. Although not shown explicitly on the basis of alternative scenarios, the establishment of water use rights alone does provide security for all types of water users, as they guarantee a long-term right to access to a specific volume of water, which can lead to investments for improved water use in all sectors, and supports longer-term cropping decisions towards more high-value (and more risky) cropping patterns. In particular, by making the limits to water use explicit, water use rights create incentives for the implementation of water-saving technologies to meet future demand. The results from the alternative clearinghouse mechanism (BRK) scenarios have shown that farmers and other water users do respond positively to changes in the incentive structure for water allocation and use. For example, water sales from irrigated areas occur more often, when rice constitutes a large share of the irrigated area in the specific demand site due to the lower value of water in rice irrigation compared to other cropping systems. Moreover, in the case of the brokerage system, special attention has to be paid to the setting of the agency-fixed water price, at which users can sell part of their water use right or obtain access to additional water. At relatively higher water purchase and sales prices, for example, at the USD 0.06/m^3 applied here, irrigators tend to sell a part of their water use right at the same time as profits from irrigated agriculture on a per hectare basis increase significantly, as water in low-value uses is sold first—here average profits per ha increased to USD 779/ha, and farmers earned an additional USD 89 million from water sales, but total profits from irrigated farming alone in the basin declined to USD 387 million. The water

sold by irrigation sites translates into real water savings at the basin level that can enhance instream flows or can be used to meet urban-industrial demands. If, on the other hand, the water purchase/sales price is relatively low, for example, at the USD $0.02/m^3$ used here, then irrigation sites will tend to purchase additional water—here for USD 27 million—resulting in lower average profits per ha, here USD 538/ha, while total irrigation profits are higher, here at USD 486 million. In this case, instream flows decline, but irrigated area and farm employment increase. Thus, the brokerage systems can help achieve water savings in irrigated agriculture without hurting the net income situation in rural areas; in fact, farmer incomes are enhanced if appropriate incentives are provided.

The brokerage mechanism has been examined here as it is relatively easier to implement in a developing-country context, once water use rights are established, as it requires no market clearing mechanism. However, as the results here have shown as well, depending on the clearinghouse-set water price (and on the water scarcity or abundance situation), large volumes of additional water might be purchased, resulting in net incomes to the agency, but net losses to the environment and possibly to hydropower production, or large volumes of water use rights are sold to the agency, in which case the environment and hydropower benefit, at a net monetary cost to the agency. The introduction of a market clearing mechanism avoids these possibly extreme—albeit within physical, technical, system, and economic boundaries—sale and purchasing events by placing a limit on water use right sales, as bids to sell water are balanced with existing demands for additional water.

Results for the series of MC scenarios have shown that although the volume of water sold and purchased is significantly reduced compared to the BRK scenarios—with maximum water volumes traded of 284 MCM under MC compared to 1,690 MCM under BRK—net gains across water-using sectors are as large or even larger compared to the BRK system. However, the

implementation of an MC scenario in practice requires a complex information and management system, with large ensuing transaction costs, which would need to be estimated in detail prior to establishing such a system.

The analyses have also shown that irrigation sites will only sell part of their water use rights, that is, the introduction of water trading does not necessarily lead to the cession of agricultural activities. According to the model simulations, if water can be sold to or purchased from a clearinghouse, irrigators spend 5.6 percent of their farm incomes on purchasing additional water (to obtain 20 percent of their surface withdrawals) at the lower agency water price. At the higher price, irrigators obtain 23 percent of their total irrigation profits from water sales, and sell 33 percent of withdrawals (or 3 percent of total basin discharge). If market clearing is introduced, 1.3 percent and 3.8 percent of the average farm income is obtained from water sales at the lower and higher water-trading price, respectively, and 5 percent of irrigation water is transferred out of agriculture.

Finally, the application of both water-trading instruments are very flexible and can adapt to the changing scarcity value of water in the basin. When water is abundant, for example, a low water price for sales and purchases can be set and most water will be used within its respective intended use. As the basin economy develops and water becomes scarcer, the agency price could be increased to reflect the higher value of water in the basin, thus prompting additional water sales and investments in water-saving technologies in irrigated agriculture as well as other water-use sectors.

Moreover, the analysis of changes in macroeconomic policies—here the full removal of primary economic distortions (taxes, subsidies) that affect irrigated agricultural production (and hence agricultural water use)—compared to the current situation has shown that the prevailing pattern of price distortions has significant impacts on water usage at the basin (and national)

levels. The removal of remaining agricultural protection and subsidies would lead to direct annual farm income increases of USD 89 million in the Dong Nai River Basin (for the future 2010 estimate). Thus, distorted input and output price policies also distort incentives for efficient land water allocation in irrigation and other water-using sectors. Efficient allocation of land and water resources at the basin level would be enhanced if policymakers remove remaining distortions at the macro level in Vietnam, and other Asian river basins.

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