Alternative Futures for Water Allocation and Use in the Dong Nai River Basin, Vietnam

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Introduction

Recent reforms in Vietnam's water sector, in combination with increasing scarcity and vulnerability of existing water resources, and declining public funding available for large-scale infrastructural investment in the sector, have led to an increased awareness for the need to analyze water-resources allocation and use in an integrated fashion, at the basin scale and from an economic-efficiency perspective.

In the time frame of only slightly more than one year, Vietnam initiated a series of major reforms in the country's water sector—including the enactment of the Vietnamese Water Resources Law in 1999, the subsequent Decision on the Establishment of a National Water Resources Council in June, 2000, and the issuance of decisions regarding the establishment of Planning Management Councils for the Red river delta, the Mekong delta, and the Dong Nai river basins (DNRB) in April, 2001. The Water Resources Law has led to a series of additional initiatives in the water sector, including the drafting of legislation regarding the licensing of groundwater and, eventually of surface water. Finally, since 1998, the Ministry of Agriculture and Rural Development (MARD) has been attempting to raise the level of irrigation service fees (ISF) collected in the country to better cover irrigation operation and maintenance (O&M) costs.

At the same time, scarcity of water resources is becoming a more common phenomenon in the country, albeit still lower in priority than the serious annual flooding problems, particularly in the Mekong delta. During the drought of early 2002, various regions in southern Vietnam saw their harvests threatened, faced depleted groundwater supplies for drinking water and land subsidence, and even experienced forest fires.

Vietnam's water resources are also becoming more and more vulnerable to increased pollution levels that have accompanied the rapid industrial and economic growth over the last decade. The Dong Nai river basin (DNRB), where slightly more than half of industrial gross domestic product (GDP) in the country is produced, is already facing high pollution levels, without adequate treatment facilities.

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Public funding for large-scale water infrastructural investment projects has been declining across the Asia-Pacific region, particularly for large-scale reservoirs and irrigation schemes. The Government of Vietnam has started to move from a supply-driven approach to investment in the sector to a more demand-based approach, including river-basin planning, a wider range of investment approaches, including build-operate-transfer (BOT) for both bulk water supply and hydropower projects as well as small private water suppliers in urban areas, and a more participatory process. But more needs to be done to accommodate increasing water demands with limited financial resources.

To make appropriate water allocation and investment decisions, an integrated approach to the resource has to be taken. This paper presents the development, application and preliminary results from an integrated economic-hydrologic river-basin model for the DNRB in southern Vietnam that attempts to incorporate these issues into one comprehensive modeling framework, as a tool to assist in decision making.

The following sections provide a brief overview of the DNRB, and then introduce the modeling framework and structure, and describe the data utilized. The second part of this paper presents a summary of baseline results, sensitivity analyses and alternative scenarios. The paper ends with some concluding remarks.

Background on the Dong Nai River Basin (DNRB)

The DNRB is the largest national river basin in Vietnam and the economic center of the country with a catchment area of 40,683 square kilometers. The basin is located in the southern part of the country and includes lowland areas that are subjected to annual flooding in the wet season and salinity intrusion in the dry season as well as mountainous highland areas rising up to 1,600 m above sea level. In addition, for administrative and analysis purposes, a series of several smaller basins on the coast[2] are combined with the main Dong Nai basin, adding to a total surface area of 48,471 km^2 within Vietnam, or about 15 percent of Vietnam's land surface area (see also figure 1).

The basin includes ten provinces and the Ho Chi Minh City (HCMC).[3] Some characteristics of these provinces are shown in table 1. As can be seen, 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. It accounts for slightly more than half of the total industrial GDP in Vietnam. Industrial production is concentrated in the HCMC—Bien Hoa-Ba Ria Vung Tau economic zone. More recently, Binh Duong province has emerged as an industrial center, with an industrial growth of 26 percent per year during 1996–1999, albeit from low levels. Moreover, whereas the total population in Vietnam increased at 1.6 percent per year from 1995 to 2000, the basin population increased at an annual rate of 2.6 percent per year during the same period, to reach approximately 14 million in 2000. Although

[2]In the following, references to the Dong Nai basin include the surrounding coastal area, unless specified otherwise.

[3]About 19.4 percent of Dak Lak, 90 percent of Lam Dong, and 51.3 percent of Long An are included in the basin area. Unless mentioned otherwise, only basin areas of these provinces are referred to.

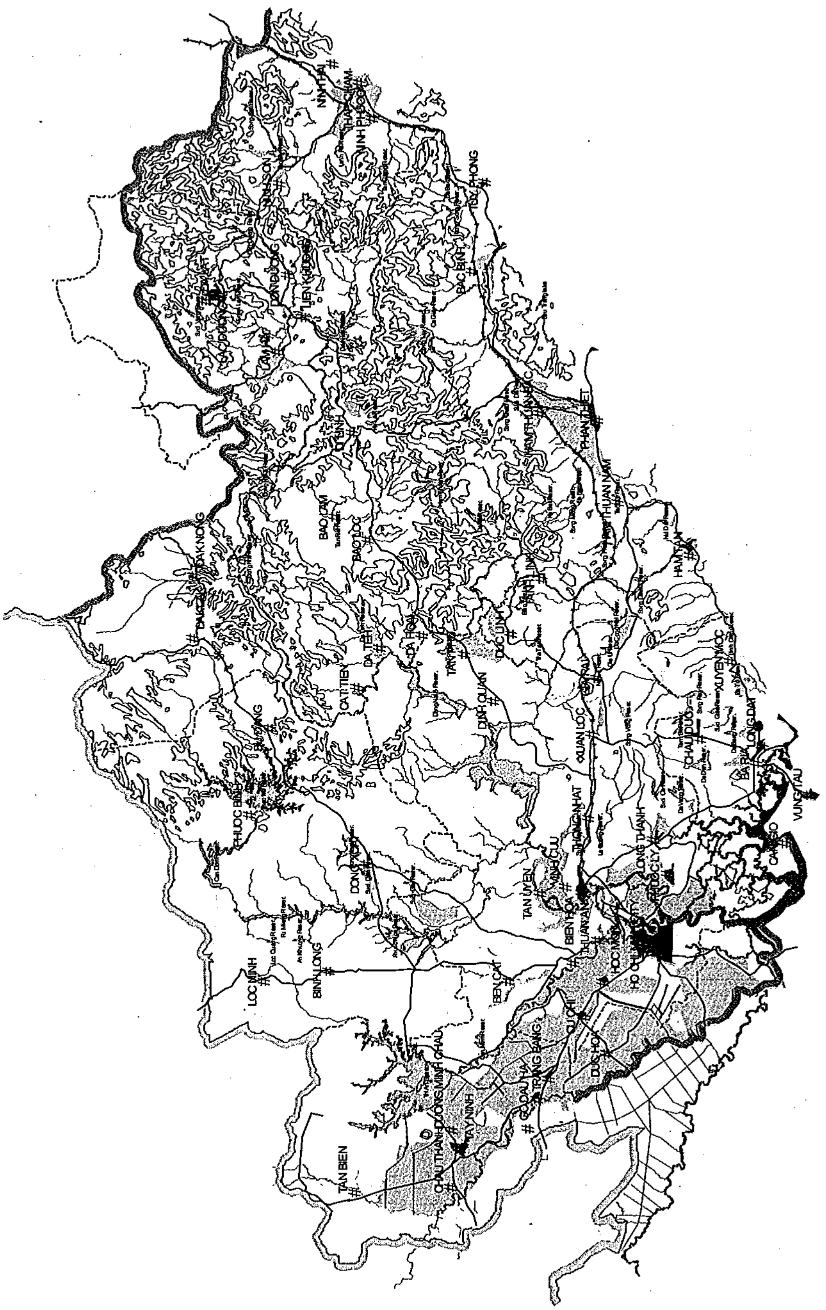


Figure 1. The Dong Nai river basin.

Table 1. Economic indicators for the provinces in the Dong Nai river basin.

	Land area 2000 (ha)	Gross irrigated area 1999 (ha)	Population 2000 ('000)	GDP 1999 (M US$)	Share agriculture GDP 1999 (%)	Share industrial GDP 1999 (%)	Income per capita 1999 (US$/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	3,137	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	5,036	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.
Source: Land area: Sub-NIAPP; Gross irrigated area: adjusted from SIWRP 1993; Population and GDP: various statistical yearbooks; Income per capita: GSO 2001.

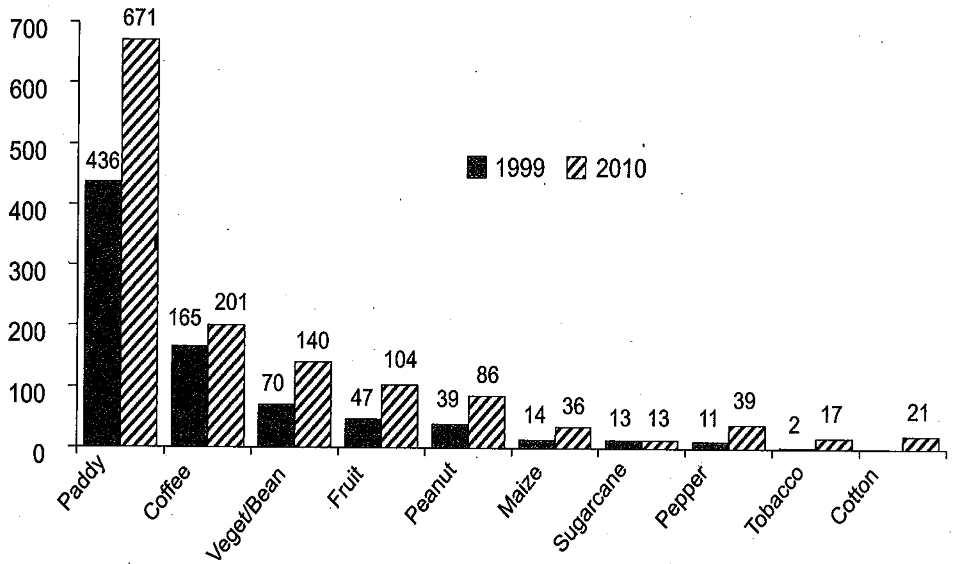
the share of agricultural GDP has been declining over time, the agriculture sector in the basin is highly diversified and dynamic, with products ranging from basic staples like rice and maize to raw materials for the local industry, including cotton, rubber, and sugarcane, to high-value crops, like coffee, fruit, grapes, pepper, tea, and vegetables. Figure 2 shows the areas of major irrigated crops for 1999 and projected for 2010. Finally, although the basin can be considered relatively rich on average, it includes some of the poorest districts and provinces in the country, in particular, Ninh Thuan and Binh Phuoc provinces as well as several rural districts in Binh Thuan, Dak Lak, and Lam Dong provinces.

The total runoff in the basin is estimated at about 47 billion cubic meters (BCM), 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 five 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. In addition to the flows from the Mekong river, the Dong Nai river transfers about 20 m^3/sec (equal to 643 million m^3) to the Cai river basin in Ninh Thuan province in the coastal region.

The basin ranks second in hydropower potential in the country. In 2000, the total installed hydropower capacity reached 1,182 megawatts with an average annual power production of 4,881 gigawatt hours. The total investment cost of existing hydropower projects is estimated at 1,105 million US dollars (Tri An, Thac Mo, and Ham Thuan Da Mi reservoirs). Selected hydropower parameters are shown in table 2. In addition, the basin includes Dau Tieng, the largest irrigation reservoir in the country. Dau Tieng was built in 1985 with World Bank-support. Although the reservoir never reached its initially designed command area of 172,000 hectares (Feasibility project no. 190 TTg dated 18/5/1979) and the later reduced area of 133,530 hectares (Decision No. 498-TTg, dated 12/10/1993), its functions have been enlarged to include indirect irrigation water deliveries for the Vam Co Dong system through canal and irrigation return flows, water supply for HCMC and other major urban centers, deliveries to major industries in Tay Ninh province, and salinity control.

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 April, 2001, MARD established a basin Planning Management Council for the DNRB (Decision No. 38/2001/QD/BNN-TCCB, dated 09.04.2001). The members of the council include several ministries involved in water-resources allocation. The Council will be chaired by the Vice Minister of MARD. Operating rules for the organization are still being worked out. However, it is anticipated that, at least at the outset, the Council will be limited to water-resources planning. ADB will support the implementation of the Council for the DNRB in an upcoming project. Moreover, since 1999, the Department of Science, Technology, and Environment of HCMC has developed plans to establish a river-basin committee focused on environmental protection in the DNRB. This process culminated recently in the proposal to the Government of Vietnam to establish a "Management Committee for the Sai Gon—Dong Nai Rivers' Basin Environmental Protection Programme" (Vietnam News, May 4, 2002). Additional information on the actors and agencies involved in water management in the DNRB can be found in Svendsen et al. 2002.

Figure 2. Irrigated harvested areas, Dong Nai river basin, 1999 and projected 2010.



Sources: 1999 data—for rice and perennial crops, Sub-NIAPP; for other crops, authors; 2010 data—Sub-NIAPP.

The combination of rapid increases on the pressure on water resources and recent reforms in water management and allocation make the basin a useful case study for competitive water uses that might occur in other basins in Vietnam or elsewhere in Asia in the future.

Modeling Framework

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). The model 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.

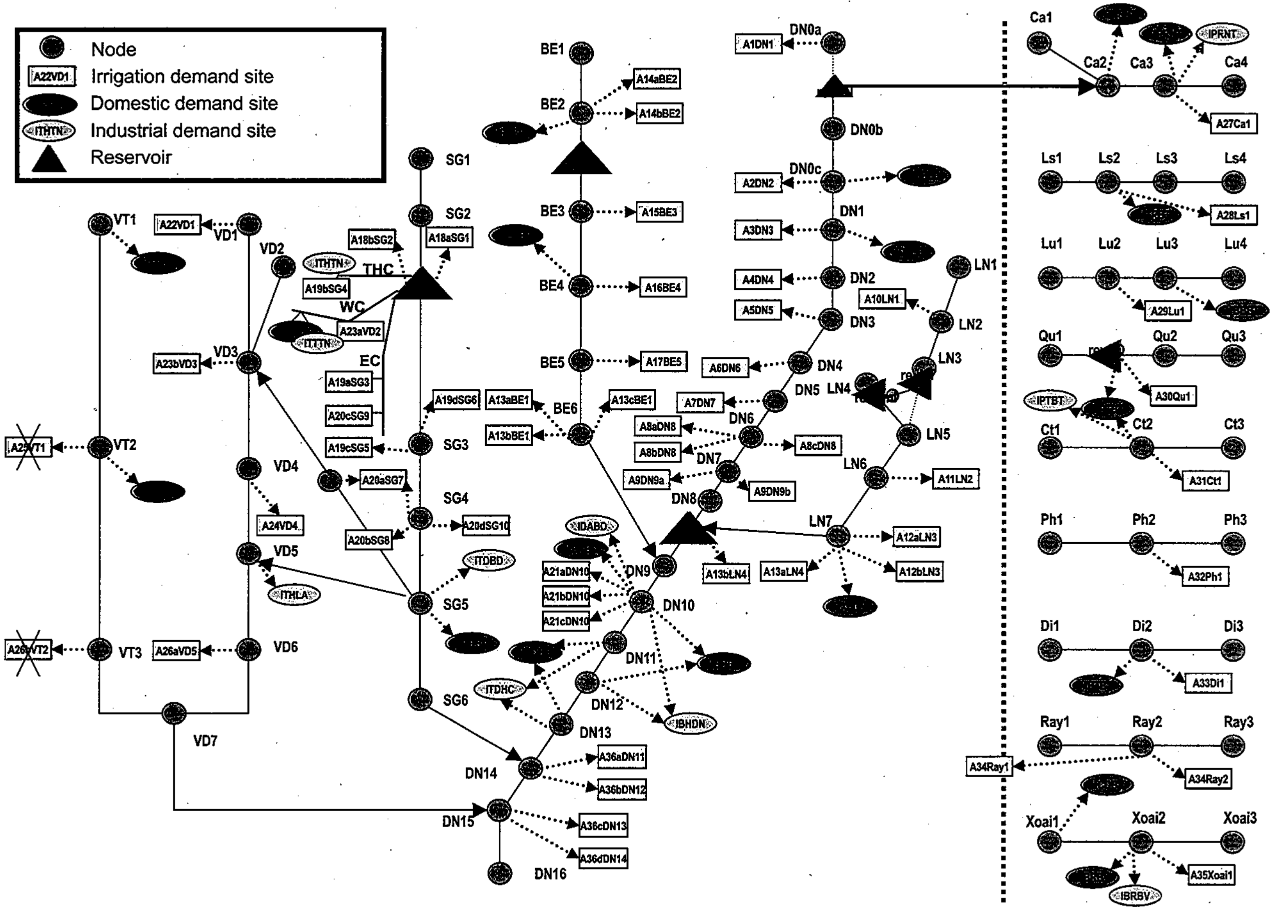
The river-basin model is developed as a node-link network, which is an abstracted representation of the spatial relationships between the physical entities in the river basin. Nodes represent river reaches, reservoirs and demand sites, and links represent the linkage between these entities (figure 3). 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.

Table 2. Existing and planned hydropower projects in the Dong Nai basin.

Name	Catchment (km^2)	Year	Uses	Capacity (MW)	Annual output (GWh)	Active storage (million m^3)	Net head (m)
Dong Nai river							
Tri An	14,800	1989	HP/FC	400	1,700	2,542	50
Dai Ninh	1,158		HP/IR/WS	300	1043	252	550
Dong Nai 1	2,804		HP	45	188	240	60
Dong Nai 2	3,141		HP	80	346	239	82
Dong Nai 3	3,612		HP	240	794	1,248	120
Dong Nai 4	3,782		HP	270	906	37	140
Dong Nai 5	54,62		HP	173	823	39	67
Dong Nai 6	6,272		HP	180	774	393	54
Dong Nai 8	9,050		HP	195	719	923	48
Be river							
Thac Mo	2,200	1995	HP	150	610	1,260	
Can Don (BOT)	3,440	Const.	HP	72	295	80	30
Fu Mieng	4,110		HP	54	242	62	43
Phuoc Hoa	5,420		IR				
Smaller Dong Nai tributaries							
Da Nhim	775	1963	HP	160	1,025	156	800
Da M'Bri	234		HP	66	295	60	350
Dak R'Tih	718		HP	105	472	175	320
Da Siat	115		HP	16	80	304	255
Song Luy	554		IR			132	
La Nga river							
Ham Thuan	1,280	2000	HP	300	957	523	250
Da Mi	83	2000	HP	172	595	17	142
La Nga 3 (Ta Pao)			IR	62			
Sai Gon river							
Dau Tieng	2,700	1985	IR/WS			1,110	
Total (pl + ex)				3,040	11,864	9,792	

Notes: FC = Flood control; HP = Hydropower; IR = Irrigation; WS = Water supply.

Figure 3. Dong Nai 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.[4] 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 less 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.

The model thus incorporates both off-stream and in-stream water uses. Off-stream uses include water diversion for irrigated agriculture, domestic uses and industrial water uses. In-stream uses include flows for hydropower generation and minimum in-stream flows to control saltwater intrusion.

Thematically, the modeling framework includes three components: a) hydrologic components, including the water balance in reservoirs, river reaches and crop fields; b) economic components, including the calculation of benefits from water uses by sector, demand site and country; and c) institutional rules and economic incentives that impact upon the hydrologic and economic components (figure 4). 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-industrial areas, wetlands, fisheries, and hydropower. Water supply and demand are balanced, based on the objective of maximizing economic benefits to water use. The time horizon of the model is one year with 12 periods (months). The following subsections describe the hydrologic, agronomic, and economic components in more detail.

Hydrologic Component

Hydrologic relations and processes are based on the flow network. Major hydrologic relations and processes include: a) flow transport and balance from river outlets/reservoirs to crop fields, and domestic and industrial demand sites; b) return flows from irrigated areas and urban-industrial areas; c) reservoir releases; d) in-stream water uses; and e) groundwater.

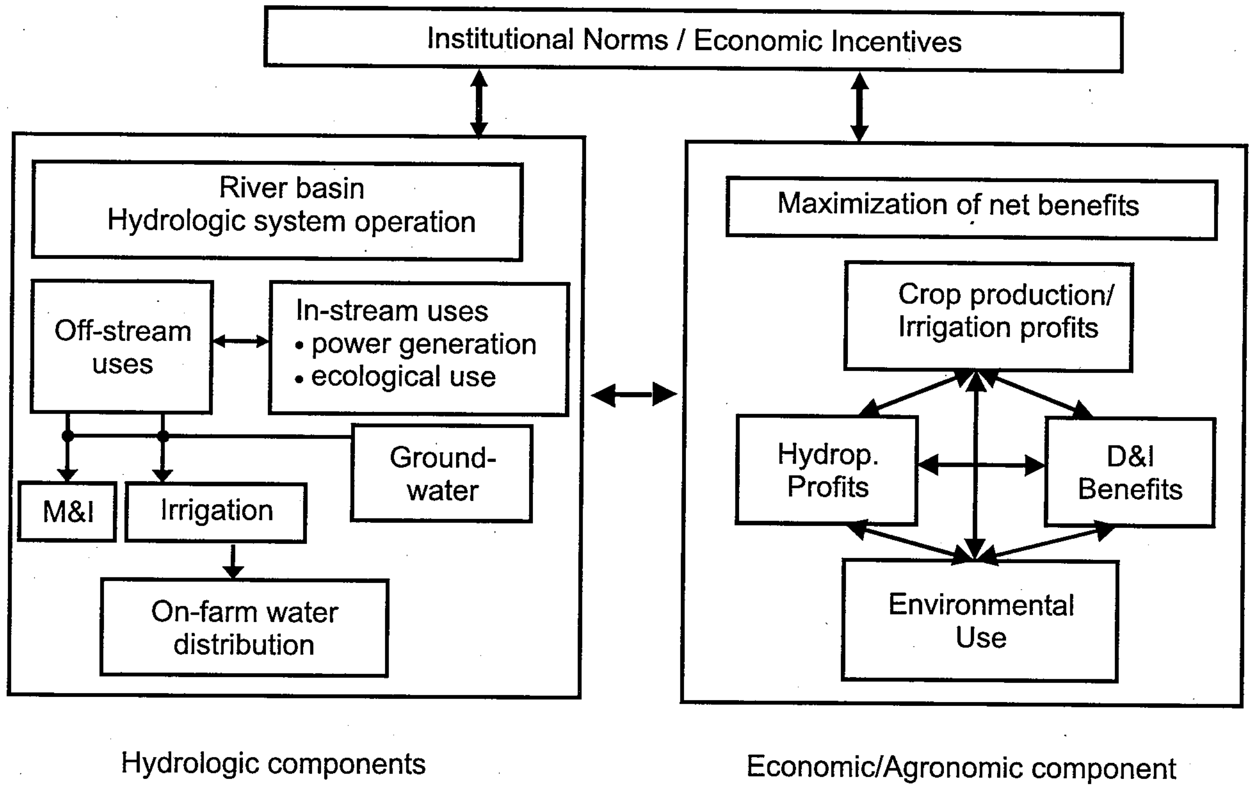
The basic flow balance at a node in the basin network is calculated as:

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

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 is included into the model as a constant parameter.

[4]Two irrigation demand sites on the West Vam Co river have so far not been incorporated as there is disagreement whether they form part of the Dong Nai river basin.

Figure 4. Model components, integrated economic-hydrologic river-basin model.



After careful analysis of existing data, it was determined that data were not sufficient for the incorporation of a (shallow) groundwater balance. Missing data include reliable recharge values, transmissivity coefficients from river to groundwater and vice versa, as well as the specific parameters for the groundwater table. As a result, only the exploitation capacity of shallow groundwater was included, and withdrawal estimates as available.

Economic Component

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

$$Max \quad Obj = \sum_{a} VA(a) + \sum_{m} VM(m) + \sum_{\text{in}} \text{VI(in)} + \sum_{\text{pw}} VP(pw) \qquad (2)$$

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 stations

Crop-Yield Function

In order to establish a relationship between water input and crop yield, a quadratic production function is chosen (see equation 2) due to its properties of decreasing marginal returns to additional inputs and substitutability of inputs.

The quadratic function is expressed as follows:

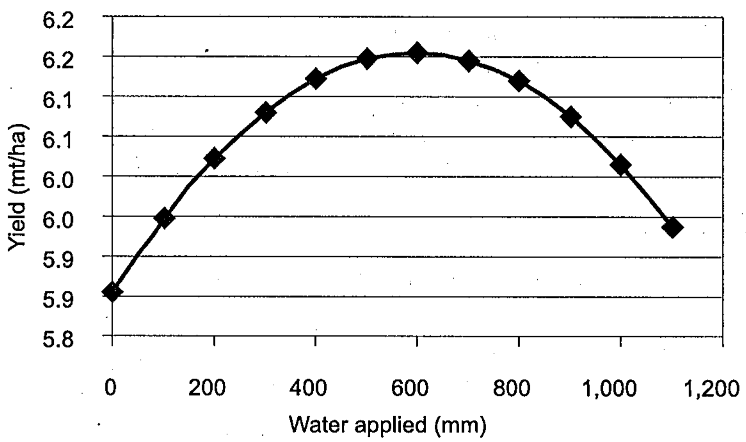
$$y(a,c) = [\alpha_1, \alpha_2, \alpha_3, \alpha_n,] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_i \end{bmatrix} + [x_1 \quad x_2 \quad x_3 \quad x_n] \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{1m} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{2m} \\ \gamma_{31} & \gamma_{32}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

where, α and γ are the input coefficients.

The quadratic yield function is estimated using the Generalized Maximum Entropy (GME) approach (Golan et al. 1996; Mittlehammer et al. 2000). GME was developed by Golan et al. (1996) and a comprehensive presentation can be found in the above references. The program that calculates the yield functions was developed by Richard Howitt of University of California at Davis, USA, and Arnaud Reynaud of INRA (Institute National de la Recherche Agronomique), in France. The yield model uses first-order conditions derived from the desired model structure and a yield function as estimating equations. This approach enables the estimation of flexible form yield function parameters in the case of limited small sample information. In this situation, conventional econometric estimates would be restricted by the ill-posed or ill-conditioned data sets. Adaptations to the original Howitt/Reynaud program include usage of cost as inputs instead of physical quantities, redefinition of water inputs to include irrigation water applied from questionnaire observations together with estimates of effective rainfall, and the estimation of yield functions instead of the earlier approach of estimating production functions.

The resulting α and γ coefficients have been incorporated into the basin model. Figure 5 shows an example of the yield function at increasing water application.

Figure 5. Yield function with water as an input, maize winter-spring season.



The net profit function for irrigated agriculture is formulated as:

$$VA(a) = \sum_{c} A(a,c) * y(a,c) * pc(c) - (lc(c) + mc(c) + fc(c) + pec(c) + sc(c)) \quad (4)$$
$$- W(a,c) * pw(c)$$

where,

A = area harvested
y = yield, calculated in quadratic yield function
pc = crop price at farm gate
lc = labor cost (family and hired)
mc = machinery/animal cost
fc = fertilizer cost
pec = pesticide cost
sc = seed cost
W = irrigation water applied
pw = water fee per m^3
c = idex for crops

Penalty Function

The seasonal crop yield function drives the seasonal water allocation among crops, but cannot distribute the water within the crop growth season according to the water requirements of crop-specific growth stages. In order to achieve consistency between the seasonal yield function and the monthly water balance in the hydrologic system a penalty term is introduced into the objective function that minimizes the difference between the maximum and average crop stage deficit due to water stress for a given crop and demand site. A crop growth stage is defined as one month. As a result, water is being allocated to crop-growing months in relation to the monthly crop-growth deficit.

The function is formulated as:
where,

$$Pen = y(a,c) * A(a,c) * pc(c) * (mdft(a,c) - adft(a,c)) \quad (5)$$

y = crop yield
A = irrigated crop harvested area
pc = crop price
$mdft$ = maximum stage yield deficit due to water stress by crop and demand site
$adft$ = average stage yield deficit
with:

$$dft(a,c) = kym(c)\ (1 - Eta(c,a)/ETm(c,a)) \quad (6)$$

where,

dft	=	monthly stage deficit by crop and demand site
kym	=	monthly crop yield response coefficient, following Doorenbos and Kassam (1979).
ETa	=	actual crop evapotranspiration
ETm	=	potential crop evapotranspiration

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 based on the household water-demand behavior survey described above separately for connected and nonconnected households. The variables included in the estimation are water use per capita per year; income per capita; and price/cost of water to the user. The estimated function is then extended to other cities and provinces through income and per capita water use shifters.

$$\ln(W)=\theta+\beta\cdot\ln(I)-\varepsilon\cdot\ln(Pw) \tag{7}$$

where,

W	=	per capita water demand
I	=	income per capita
Pw	=	water fee
e	=	price elasticity of demand
b	=	income elasticity of demand

The inverse of the demand function is then integrated over the space of W_0[5] - W to estimate the consumer surplus:

$$CS(W)=VM(m)=\frac{e^{(\alpha/\varepsilon)}\cdot Y^{(\beta/\varepsilon)}}{\left(1-1/\varepsilon\right)}\cdot\left\{W(m)^{(1-1/\varepsilon)}-W_0(m)^{(1-1/\varepsilon)}\right\}-W(m)\cdot Pw(m) \tag{8}$$

The income variable was treated as a constant. An example of the net benefit function is shown in figure 6.

Industrial Net Profit Function

Due to sparse data, the industrial net profit function is derived from a double log function, which relates several years of estimated industrial water-use data to industrial GDP for major industrial provinces in the DNRB.

[5]There are no clear guidelines for choosing W_0. Here it is defined as average 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.

The function is formulated as:

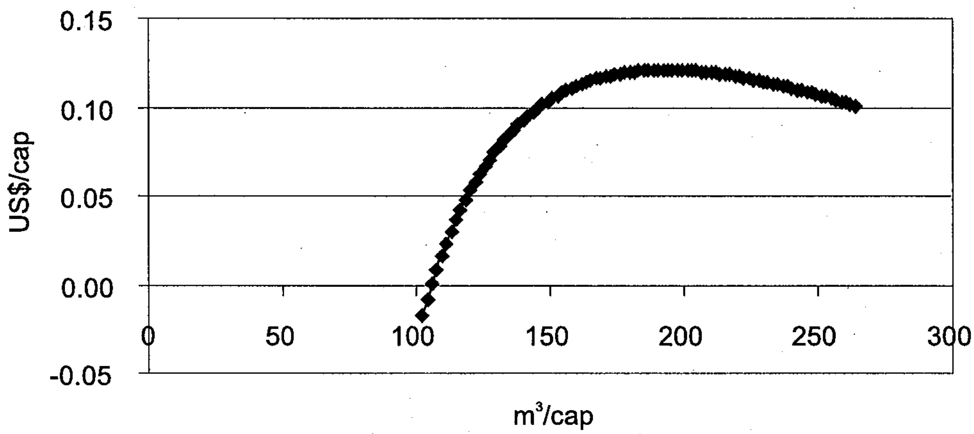
$$\ln(Ip) = \delta + \chi \cdot \ln(W) \qquad (9)$$

where,

Ip = industrial production (proxied by industrial GDP)
W = water withdrawn
c = *water supply elasticity*

For the net profit function—similar to the domestic net benefit function—only withdrawals over and above average observed or "normal" are included into the calculation. The function is formulated as:

Figure 6. Net benefit function, domestic water use, MBBT, rural areas.



$$VI(in) = (\exp(Ip(in)) - \exp(Ip_0(in))) - (W(in) * Ic(in)) \quad (10)$$

where,

Ip = industrial profit at model water withdrawals

Ip_0 = industrial profit at normal withdrawals

W = total water withdrawn

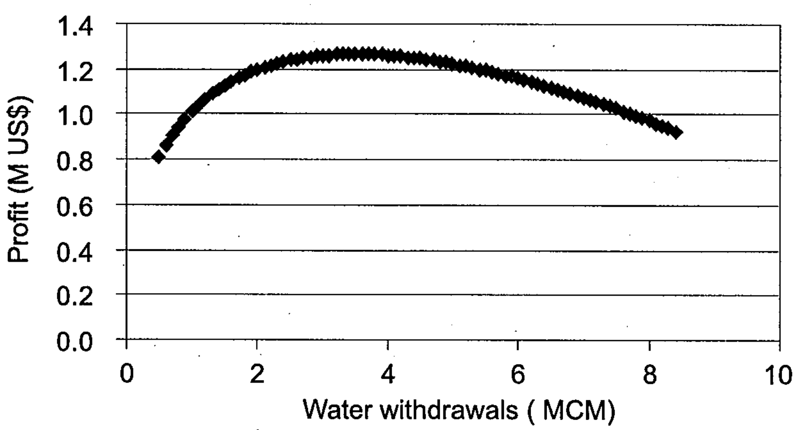
Ic = industrial withdrawal cost

An example of the net profit function is shown in figure 7.

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:[6]

Figure 7. Net benefit function, industrial water use, ex. Bien Hoa, Dong Nai Province.



[6]See also Linsley et al. 1991.

$$eff(pw) = \frac{Pow(pw) * 1000}{Q(pw) * (h(pw) - t(pw)) * 24 * 9.8} \quad (11)$$

where,

Pow = *electricity production ('000 kwH)*

Q = *flow through turbine (MCM)*

h = *head (m)*

t = *tail-water level (m)*

In order to calculate power production, equation (11) is solved for *Pow(pw)* and parameters are adjusted for monthly production. *Q(pw)* and the *h* are decision/intermediate variables in the model.

The reservoir head for power production and the reservoir area to determine net evaporation are calculated based on estimated reservoir topologic equations relating reservoir storage and height, and area and storage, respectively:

$$RST(pw,t) = a(pw) * h(pw,t)\text{^}3 + b(pw) * h(pw,t)\text{^}2 + c(pw) * h(pw,t) + d \quad (12)$$

$$RA(pw,t) = e(pw) * RST(pw,t)\text{^}3 + f(pw) * RST(pw,t)\text{^}2 + g(pw) * RST(pw,t) + i \quad (13)$$

where,

RST = reservoir storage (MCM)

RA = reservoir area (km^2)

a-i = coefficients

h = head (m)

t = period

Profit from power production *(VP)* is calculated as a linear function, multiplying power production *(Pow)*[7] with the difference between power selling price *(pp)* and power production cost *(pc)* for each hydropower station. The calculation of net profit from hydropower production does not include capital costs, which are considered sunk costs in this model.

$$VP(pw) = Pow(pw) \cdot (pp(pw) - pc(pw)) \quad (14)$$

[7]The power variable here is for million kwH.

Model Data and Calibration

The model is calibrated to 1999/2000 data. In the following section, data sources for the model are briefly described and selected baseline results are compared with observed/actual data. Further calibration efforts, under the assumption that the actual observed situation reflects the optimal outcome for the baseline, will be implemented in the next modeling phase.

Hydrologic Data

Source flow was determined by the hydrology division of the Sub-Institute for Water Resources Planning (SIWRP) based on a rainfall-runoff model called RRMOD or Rainfall-Runoff Model based on rainfall during 1978–1998 for a total of 37 nodes. Together with the withdrawal nodes, altogether 82 nodes are included in the model. Runoff at 25 percent, 75 percent, and 90 percent probability levels was also estimated by SIWRP. Total discharge amounts to 47.065 BCM. As these data are ex-post depletion,[8] estimated actual depletion is added to these observed natural flows. Approximately 4 BCM are added. Baseline model discharge amounts to a slightly larger 48.378 BMC.

A minimum in-stream 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, the DNRB has specific minimum flow requirements to control saltwater intrusion and secure a safe drinking water supply for the lower basin, chiefly HCMC. A minimum downstream flow requirement of 85 m^3/sec has been included on the Dong Nai river at the Binh An water-supply plant. On the Sai Gon river a minimum flow requirement of 25 m^3/sec was included at the location of the future Ben Than water-supply plant.

Shallow groundwater capacity is largest in the Lam Dong province and lowest in Long An (only including the basin area).

Agricultural Data

The parameters for the crop-yield function were collected by the Sub-National Institute for Agricultural Planning and Projections (Sub-NIAPP) in an extensive farm household survey covering 700 households in the 11 provinces of the basin. The survey covers crops from the summer-autumn season of 1999 to the winter-spring season of 2000. Functions were estimated for the major annual crops (bean, maize, peanut, sugarcane, tobacco, and vegetables) and perennial crops (coffee, fruit trees, other trees, and pepper) in the basin; annual crops are separated by season (winter-spring, summer-autumn, and rainy season). Moreover, rice and vegetables are further subdivided by region (coastal area, mountainous area, and lowland area). The input variables incorporated are in US$/ha: labor, machinery, fertilizer, pesticides, seeds, and water. Family labor is valued at the prevailing wage rate stipulated by the farm households. Water includes both irrigation water applied and effective rainfall. Whereas irrigation water

[8]Depletion refers to water that cannot be reused in the system.

applied was solicited in the survey, effective rainfall was estimated based on daily rainfall data prevailing during the survey implementation.

Irrigation service fees (ISF) in Vietnam for public systems are decided at the provincial level following national government guidelines. ISF are area-based and can vary by crop, season, and type of irrigation water supply (gravity or pump irrigation). In some cases, fees differ by district. Currently, fees 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. For the study here, irrigation costs include all costs related to irrigation provision, including family and hired labor, ISF, and private pumping cost. Irrigation costs from the survey have been divided by the quantity of water applied to proxy volumetric charges. According to survey observations, the water fee is largest for vegetables in the winter-spring and summer-autumn seasons in coastal and mountainous provinces, and lowest for rice crops in the rainy season. Currently, only one average fee per crop type is incorporated in the model. However, the averaging of irrigation costs across different climatic conditions in the basin causes negative profits from irrigation in many irrigation zones. Another reason for negative profits is the valuation of family labor at the prevailing farm wage rate. As a result, for the baseline, only 50 percent of the surface irrigation fee is applied. The groundwater pumping fee is set at 0.07 US$/$m^3$, which reflects typical pumping costs.

There are no consistent databases for irrigated area and irrigation sources in Vietnam. Irrigation and Drainage Management companies collect data for public systems, but even these data can be confusing as distinctions between potential command area, actual area served, and area contracted are not always clear. Detailed data, by season and type of irrigation, are usually only available for paddy. Upland crops are not separated. Private (pump and well) irrigation is not recorded. Sub-NIAPP estimates gross irrigated area for 1999/2000 at 819,136 ha, whereas SIWRP estimates it at 781,349. These estimates do not include irrigation areas located in the west Vaico river system. For this analysis, upland crops were distributed according to statistical yearbooks and survey results. It was assumed that only perennial crops are irrigated. The groundwater irrigation shares have been derived from Sub-NIAPP data.

The yield function and costs are applied to the gross irrigated area for 1999 of 759,480 hectares.[9] Area is constrained between 0.4–1.2 of the actual area irrigated during 1999/2000. the total area at each irrigation demand site is constrained to actual levels.

Only sparse data are available for return flows in the basin. According to Water Resources University (1999), overall return flows in Ninh Thuan average 20.3 percent. Other reports document 19.96–23.2 percent for the Mekong delta (similar soils as in Long An part of Tay Ninh) and 21.2 percent in the highland areas. Recent canal-lining efforts in the DNRB and elsewhere in Vietnam are expected to increase distribution efficiencies from 70 percent to 90 percent (personal communication, Ninh Thuan and Cu Chi Irrigation and Drainage Management Companies). In the model, return flows are estimated to include one-third of the percolation on the crop fields (from both surface water and groundwater withdrawals), and one half of the losses occurring during distribution and conveyance. Average return flows in the model thus amount to 26.7 percent.

[9]Adjustments to the SIWRP area included treating sugarcane as an all-year crop and deletion of irrigated areas in the wet season, where irrigation is not considered necessary, based on CROPWAT estimates.

Domestic Water Use Data

There is no database for domestic water use in the basin. Therefore, data were collected separately from water supply companies.[10] Water-loss rates were applied for surface water supply based on the data collected from the public-supply system. They varied from an average loss rate of 19 percent for Ba Ria-Vung Tau (BRVT) to 49 percent in the Trang Bang, Tay Ninh Province. Water tariffs from public supply companies were included as available. About half of the companies apply progressive tariffs. Average tariffs varied from VND 1,600/m^3 (US$ 0.11/m^3) for Long An Province to VND 2,529/m^3 (US$ 0.18/m^3) in Da Lat City, Lam Dong Province. For individual pumping and most rural domestic water uses, a supply cost of US$ 0.1/m^3 was assumed.

According to the information by the water supply companies in the basin, deliveries in 1999/2000 amounted to 683,000 m^3/day, 83 percent of which was supplied from surface water. This translates into an average delivery of 48 l/cap/day. However, 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 nonconnected households. HCMC's water supply company, for example, served 55 percent of the city's population in 2002. For those districts and areas without public supply, a minimum supply standard of 40–50 l/cap/day was assumed. This results in a 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 nonconnected households based on the 1995 household water demand behavior survey carried out by GKW/SAFEGE (1996).[11] The survey was carried out in the 12 inner and 4 peripheral districts of HCMC. The parameters estimated for the domestic benefit function are shown in table 3. The price and income elasticities estimated were then applied to other districts in the basin, following adjustments for rural-urban shares (to which nonconnected and connected parameters were applied), rural-urban incomes, rural-urban water prices, and rural-urban consumption shares. In the model, total domestic water demand is constrained between 0.6 and 2 times the observed and estimated water usage.

Industrial Water Use Data

There is no agency in charge of monitoring industrial water-use data. Estimates of industrial water use in the Dong Nai basin have ranged from 130 to 2,500 million m^3 per year (Ngoc Anh 2000; Boggs). For this study, industrial water use was collected for the industrial zones of the four major industrial provinces in the basin (Ba Ria Vung Tau, Bin Duong, HCMC, and Dong Nai). However, data were available only for some of the zones. In addition, substantial industrial

[10]Binh Phuoc has no water supply company and no data were collected in Dak Lak province, as only two rural districts are included in the basin area.

[11]GKW and SAFEGE are German and French consulting companies, respectively, which carried out ADB TA 2000-VIE.

Table 3. Household Survey, Sample Information

	Connected HH	Non-connected
Constant	-0.36846	-0.66096
	(2.1)	(2.9)
ln(income)	0.40434	0.32252
	(12.4)	(4.5)
ln(price)	-0.17327	-0.30259
	(3.0)	(10.0)
Av. Demand (m^3/m/cap)	4.9	2.4
Av. Price(US$/$m^3$)	0.11	0.67
Av. Income (US$/m/cap)	36.9	24.8
Observations (No.)	894	187

Note: Absolute value of t-statistics in parentheses. Coefficients from double-log function. Av. = Average.

production takes places outside of designated industrial zones. Industrial water supply was also collected from municipal water-supply companies in the various provinces in the basin, when available. As these data were still not sufficient, industrial water use was estimated based on the water-use coefficients for industrial products shown in table 6 in Boggs 1995. The calculated industrial water-use data for the years with available data are shown in table 4. The regression estimates for industrial water use and GDP by province are shown in table 5.

In 1999, the total net industrial water demand was estimated at 287 million m^3, 44 percent of which was delivered from surface-water sources and 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 the Long An Province at VND 2,600/m^3 (US$0.19/$m^3$) and highest in Binh Thuan Province at VND 4,500/m^3 (US$0.32/$m^3$). For modeling purposes, water abstractions are constrained between 0.7 and 1.8 of estimated actual withdrawals.

Hydropower Data

Historic daily reservoir release data as well as power production for the major existing reservoirs in the DNRB, Da Nhim, Thac Mo, and Tri An, were obtained from the Power Engineering Consulting Company 2 (PECC2) in HCMC for at least three consecutive historic years. The Hàm Thuan and Da Mi power stations started operating only during 2000. Therefore, no historic records could be obtained. Design parameters were used for these two hydropower stations.

Other parameters incorporated include dead and maximum storage, maximum turbine flow, power-production efficiency, and the area-storage and elevation-storage relationships. Moreover, reservoir operation curves that set monthly standards for minimum reservoir height and storage to secure minimum water availability as well as maximum reservoir height for flood control have been incorporated as constraints into the model. The introduction of the operation

Table 4. Industrial water use, DNRB provinces, 1995-1999 (million m^3).

	1995	1996	1997	1998	1999	1995-1999 (%/yr.)
Ba Ria Vung Tau	14.0	28.7	38.6	45.4	45.8	34.5
Binh Duong	12.4	26.9	47.9	59.4	94.0	65.9
Binh Phuoc	0.5	0.5	0.5	0.7	0.9	17.5
Binh Thuan	0.5	0.7	0.8	0.9	1.2	22.4
Dac Lac	6.6	6.8	7.4	8.2	8.2	5.6
Dong Nai	na	252.9	269.6	246.5	280.4	3.5
HCMC	177.0	174.6	212.6	283.7	295.6	13.7
Lam Dong	1.1	2.1	3.8	3.9	3.6	34.0
Long An	6.9	101.0	99.9	94.9	100.2	95.1
Ninh Thuan	0.9	1.1	1.5	1.9	2.4	26.3
Tay Ninh	3.3	3.0	3.4	4.3	6.0	16.4
Total	223.3	598.4	686.0	749.8	838.2	39.2

Note: Calculation refers to administrative, not basin boundaries; calculation based on water use coefficients for industrial products, as presented in Boggs 1995. Data on industrial products included in provincial yearbooks varies by province and are therefore not necessarily consistent across provinces.
Source: Boggs 1995 and various provincial statistical yearbooks.

Table 5. Regression estimates for GDP and water input.

	Intercept	Water coefficient
Ba Ria-Vung Tau	0.32701	1.59029
Binh Duong	0.84041	1.06091
Binh Thuan	3.58741	1.45063
Dong Nai	3.38966	0.45416
HCMC	0.83447	1.21217
Long An	2.12296	0.46874
Tay Ninh	2.69079	0.72138

Note: Coefficients from double-log estimates.

curves significantly constrains tracing out optimal reservoir-operation strategies and, as a result, hydropower profits are constrained within a narrow margin. Reservoir-operation curves are not adhered to religiously in the basin, particularly during very high (2000) and low flow years (1998).

Hydropower production costs, supplied by PECC2, for the major stations, range from US$ 0.012/kWh for the Thac Mo station to US$0.033 for the Ham Thuan and Dami stations; and electricity selling prices range from US$0.038/kWh for Tri An to US$0.07/kWh for the Da Nhim station. For analysis purposes, it is assumed that hydropower profits accrue to those provinces where the reservoir is located.[12]

The model has been coded in the GAMS modeling language, a high-level modeling system for mathematical programming problems. The CONOPT2 solver for highly nonlinear problems has been utilized.

Baseline Results

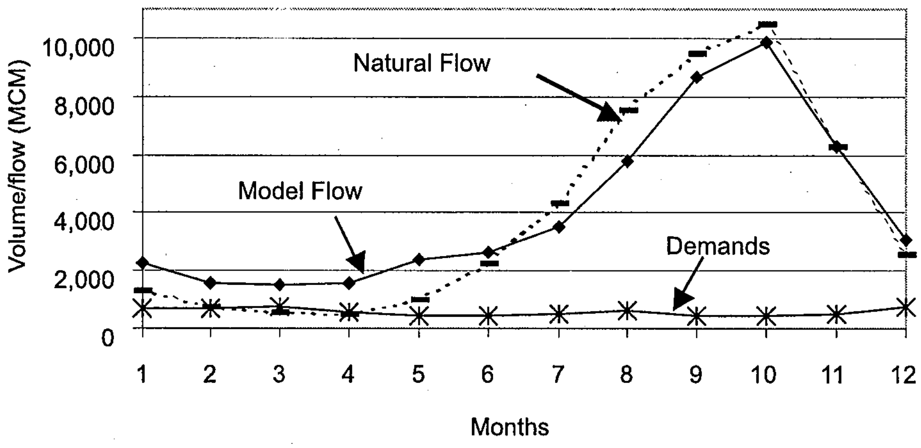
In the baseline, water withdrawals to off-stream demand sites and in-stream flow demands are driven by the objective of maximizing basin benefits from water use subject to a series of physical and system-control constraints as well as minimum in-stream and downstream flow requirements.

The total off-stream water withdrawals are estimated at 3,465 million m^3, 7.4 percent of the total runoff. Altogether 2,312 million m^3 are withdrawn for irrigation, 542 million m^3 for domestic uses, and 612 million m^3 for industrial uses. Minimum flow requirements for drinking water on the Dong Nai and Sai Gon rivers account for a further 3,469 million m^3. In addition, the total groundwater abstractions amount to 284 million m^3 or 2.8 percent of the total shallow groundwater capacity. About 100 million m^3 are pumped for irrigation, 158 million m^3 for domestic uses, and 23 million m^3 for industrial uses. The total power production amounts to 5,284 GWh.

Figure 8 shows the distribution of natural flows, model flows, and water demands across the year for the baseline solution. A few observations can be made based on this graph. First, it clearly shows the large variation in flow between the dry and rainy seasons, even after the construction of the three major reservoirs in the basin (model flow). 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 reservoir) flows during March and April, by 214 million m^3 and 56 million m^3, respectively. Finally, existing reservoir storage can accommodate only about a doubling of total demands during the dry season, and plans for future reservoirs, which are chiefly for hydropower production, can only accommodate some additional dry-season demands (see also the 2010 scenario discussed later in this paper).

[12]This is an issue in the case of the already existing Da Nhim and the future Dai Ninh reservoirs; the reservoirs are located in Lam Dong Province, but the hydropower stations are in Ninh Thuan and Binh Thuan provinces, respectively.

Figure 8. Baseline flows and withdrawals.



Based on this graph, the DNRB can be characterized as an "open" river basin, where 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 in-stream water needs compete with each other during the dry season. In the so-called "closed" basins, finally, there is no excess water flowing out of the basin; all water resources are committed to use (Keller et al. 2000). The latter state is unlikely to occur in the Dong Nai basin.

Table 6 shows the baseline profits by province in the basin. The total profits add to US$ 2,123 million; 48 percent from industry, 29 percent from domestic uses, 15 percent from irrigation, and 7 percent from hydropower production. HCMC achieves the largest profit from water use. Industrial water-use profits are concentrated in the lower basin area, chiefly HCMC, Dong Nai, and Tay Ninh provinces. Benefits from domestic water use are by far the largest in HCMC. Irrigation profits are largest in the Lam Dong and Tay Ninh provinces, followed by Binh Phuoc and Ninh Thuan. Hydropower profits are the largest for Ham Thuan-Da Mi station, followed by Da Nhim in the Lam Dong Province. This result reflects the large participation of nonagriculture sectors in the basin water economy, although irrigation is by far the largest water user in the basin.

Table 6. Baseline scenario, profits from water use.

	Irrigation	Domestic	Industry	Hydropower	Total
Ba Ria - Vung Tau	10.7	12.7	55.7	79.1	—
Binh Thuan	28.5	30.7	19.3	54.8	133.3
Ninh Thuan	36.2	7.9	54.7	—	98.7
Coastal	75.3	51.3	129.8	54.8	311.2
Binh Phuoc	44.0	16.7	—	29.2	89.8
Dak Lak	8.4	0.4	—	—	8.8
Lam Dong	61.0	77.1	—	39.9	178.0
Mountain	113.3	94.3	—	69.1	276.7
Binh Duong	10.7	26.1	45.8		82.6
Dong Nai	15.7	78.7	265.8	31.6	391.7
HCMC	19.6	335.0	285.0	—	639.7
Long An	26.6	17.8	35.7	—	80.2
Tay Ninh	62.0	11.4	267.5	—	340.9
Lower Basin	134.6	469.0	899.7	31.6	31.6
Basin Total	323.3	614.5	1,029.5	155.5	2,122.8

Table 7 shows the difference between actual and model area allocation. According to the model result, the total area is lower by 6,063 hectares. The largest percentage decline occurs for sugarcane, whereas the largest absolute net decline occurs for rice. However, among the various paddy crops, winter-spring and summer-autumn paddy in the lowland areas actually increase in actual area, as does rainy season paddy in the coastal area. Water withdrawals (net of conveyance and distribution losses) are by far the largest in February and March at around 225 million m^3. Withdrawals are the largest for perennial crops and paddy. Coffee withdrawals add to 354 million m^3 or 26 percent of the total withdrawals. All paddy crops taken together account for 686 million m^3 or 50 percent of the total withdrawals. Crops grown during the rainy season and short-duration crops show the lowest withdrawal quantities.

The variation in the contribution of rainfall to water consumption varies substantially for irrigated crops, and depends on location, and on planting and harvesting dates, among other factors. Water application per hectare is largest for the perennial crops: coffee, fruit trees, other trees (largely grapes in the Ninh Thuan Province), pepper and sugarcane. However, effective rainfall might actually be lower for perennial crops as they already take up substantial shallow groundwater through their extensive root zone. Paddy crops rank second in water application. Vegetables, on the other hand, have the lowest crop-water demands. The share of effective rainfall in total crop-water consumption is above 50 percent for most of the crops. It is only lower—accounting for about a third of the total consumptive use—for several dry-season planted crops, like bean, peanuts, rice, and tobacco.

Table 7. Irrigated area, actual and baseline result.

	Area, 1999/2000 (hectare)	Change in area, model	Change (%)
Bean	6,294	1,203	19
Coffee	101,041	4,525	4
Fruit tree	19,800	3,105	16
Maize	13,906	2,781	20
Other tree	1,603	321	20
Peanut	38,652	7,730	20
Pepper	4,591	918	20
Rice	494,983	-38,368	-8
Sugarcane	12,650	-1,470	-12
Tobacco	2,450	490	20
Vegetables	63,510	12,702	20
	759,480	-6,063	-1

Note: 20% denotes the upper limit in area change.

Table 8 presents the net profit per hectare and the productivity of irrigation water for the basin crops. Net profits per hectare are largest for the category "other tree" (largely grapes), followed by pepper, and some of the vegetable crops. Profits per hectare are lowest for several of the rice crops and sugarcane. The productivity of irrigation water, defined as US$/m^3, depends on both the profitability of the crop and its need for irrigation water. Baseline results indicate that water productivity is highest for vegetable crops,[13] followed by pepper, bean grown during the rainy season, and the category of "other trees." Water productivity is lowest for sugarcane, followed by various paddy crops.

Figures 9–12 present the marginal values for the various water uses in the basin. Figure 9 shows the monthly marginal value for irrigation water averaged across the basin-demand sites. The shadow price is largest in March at US$0.014/m^3 and averages US$0.006/m^3 across the year (without taking negative values into account).[14] Figure 10 shows the marginal value of water in hydropower production averaged across power stations. The marginal value is highest during the dry season and almost mirrors the discharge curve of the basin. It averages US$0.02/m^3 and variations across the year are very small due to the operation curve imposed in the model. The marginal value curves for domestic and industrial uses (figures 11 and 12) are similar in form, but differ substantially in value. The marginal value for domestic uses

[13]The very high water productivity of coastal rainy season paddy is due to very low irrigation water demand for that particular crop.

[14]Negative shadow prices are due to the lower bounds in area set in the model.

Table 8. Baseline scenario, net profit per hectare and productivity of irrigation water by crop.

	(US$/ha)	(US$/m³)
Other trees	7,986	0.940
Pepper	5,484	1.558
VegiDXc	4,335	0.724
VegiMUAc	4,275	3.739
VegiHTc	4,073	0.603
TobaccoDX	2,506	0.498
BeanMUA	1,599	1.131
VegiMUAm	1,592	6.448
VegiHTm	1,558	1.655
BeanHT	1,506	1.051
Fruit trees	1,215	0.189
VegiDXu	1,015	0.448
VegiDXm	875	0.275
VegiHTu	839	0.351
VegiMUAu	666	0.777
Coffee	636	0.113
PeanutDX	299	0.105
MaizeDX	203	0.061
RiceDXc	180	0.047
RiceHTc	180	0.106
MaizeHT	166	0.119
RiceHTm	139	0.035
PeanutHT	136	0.200
RiceDXu	114	0.041
Sugarcane	109	0.024
RiceDXm	105	0.032
RiceHTu	105	0.029
RiceMUAm	94	0.105
RiceMUAu	92	0.029
RiceMUAc	70	67.927

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).

averages US$0.18/m^3 and peaks in February at US$0.29/ m^3. The marginal value for industrial use is much higher, averaging US$13/m^3 and peaking at US$13.5/m^3 in February. This very high marginal value is due to the current specification of the industrial water-use function that directly links water as an input with industrial GDP as an output.

Alternative Scenarios

Sensitivity Analyses

Sensitivity analyses are carried out to test the robustness of baseline results. Parameters tested include changes in inflow level, field application efficiency, irrigation fee, domestic water tariff, industrial tariff and selected crop prices. All in all, model results shift very little due to changes in those parameters (unless bounds incorporated into the model are relaxed or shifted); another indicator for the relative water abundance in the basin. Results are presented in table 9.

Figure 9. Maginal value, averaged across sites, irrigation.

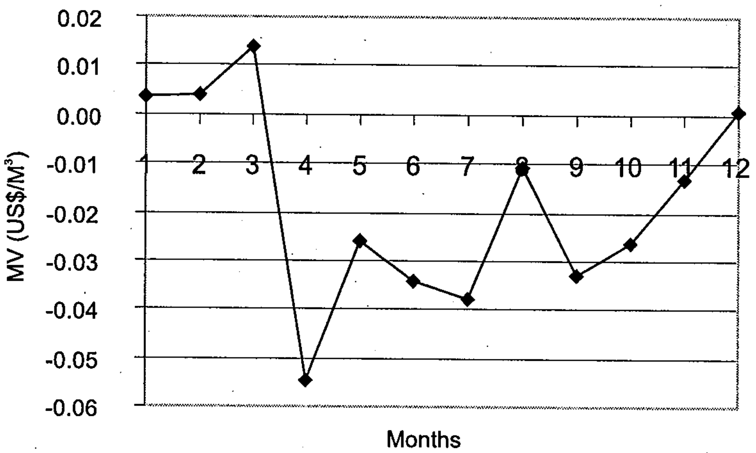


Figure 10. Marginal value, averaged across stations, hydropower.

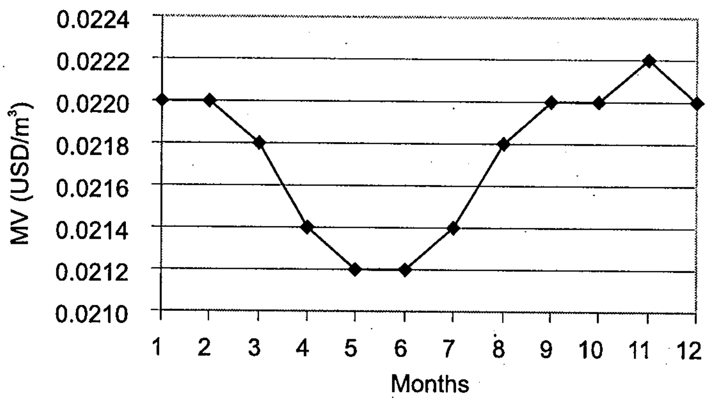


Figure 11. Marginal value, averaged across sites, domestic uses.

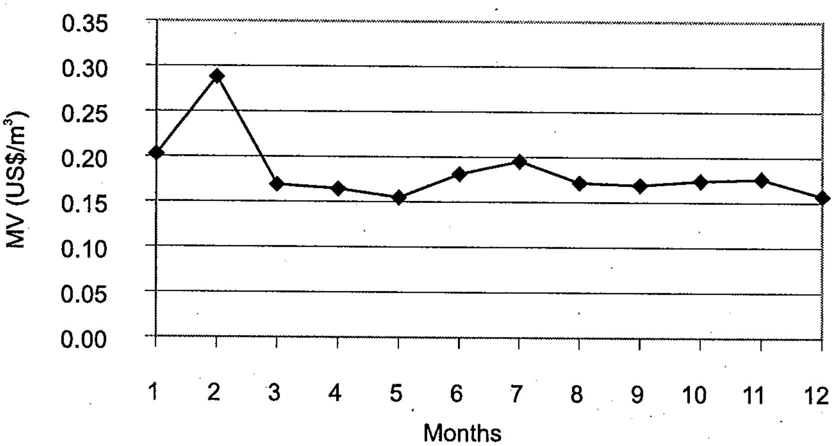
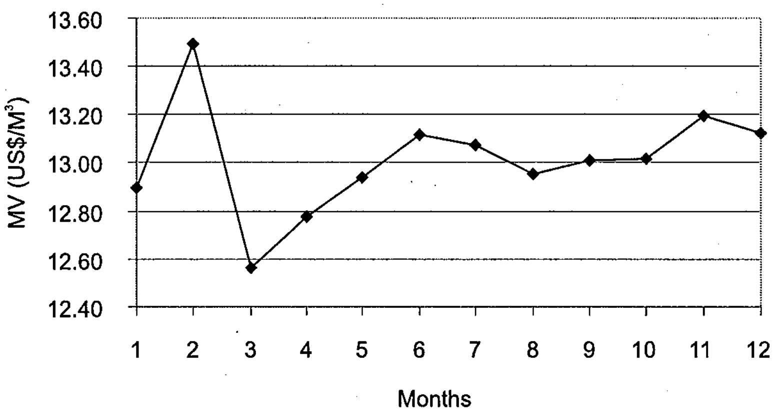


Figure 12. Marginal value, averaged across sites, industrial uses.



A high-flow year (inflows and effective rainfall at the 25% probability level) leads to a substantial increase in basin profits of 21 percentage points. Profits increase across sectors, led by industry, due to the high marginal value of water used in industry. At the same time, agricultural water withdrawals, including pump irrigation, decline due to the availability of additional effective rainfall.[15]

Inflows and effective rainfall at the 75 percent probability level, simulating a low-flow year, reduce total profits by less than 1 percent. However, irrigated area declines by 3 percentage points and agricultural withdrawals by 5 percent compared to baseline levels. In addition, hydropower profits drop by 9 percentage points due to reduced inflows into reservoirs. Finally, due to decreased surface flows, industrial groundwater pumping increases by 17 percent over baseline levels.

A further reduction in inflow levels reduces total profits only slightly more. Hydropower production is again affected most, declining to 82 percent of baseline levels. Irrigation profits drop by 2 percentage points. The share of groundwater pumping increases, but total irrigation withdrawals decline by 13 percent compared to baseline levels. Irrigated area declines by only 4 percent, indicating that those crops that consume most of the water have been taken out of production. In addition, pumping of both industrial and domestic groundwater increases, whereas total withdrawals decline.

[15]These results are based on a relaxation of upper bounds for withdrawals.

Table 9. Sensitivity analyses, various parameters.

Parameter	Levels/ values	Irrigation profit	Domestic benefit	Industiral profit	HP profit	Total profit	Irrigation area	Total withdr	Agriculture pumping	Total dom withdr	Domestic pumping	Total industrial withdr	Industrial pumping
Inflow/Eff. Rain	25% prob.[a]	108.23	112.78	131.32	105.72	120.56	106.99	98.98	90.83	130.41	132.35	111.84	126.85
	75% probability	99.71	100.00	100.00	91.45	99.33	96.98	94.71	95.42	100.02	100.96	99.84	117.31
	90% probability	97.69	99.91	100.00	81.67	98.28	95.65	86.56	105.60	99.03	109.32	99.50	154.28
Irrigation	0.5[b]	97.33	100.00	100.00	99.16	99.53	93.35	113.86	113.11	99.99	100.05	100.00	100.00
Efficiency	0.9[b]	101.63	100.00	100.00	100.45	100.28	103.89	92.02	93.28	100.00	100.00	100.00	100.00
Irrigation water price	zero	123.11	100.00	100.00	100.00	103.52	116.20	330.65	163.58	99.57	104.01	99.91	109.24
	water applied	95.71	100.00	100.00	100.00	99.35	91.75	78.69	98.90	100.00	100.00	100.00	100.00
	full cost	89.36	100.00	100.00	100.51	98.42	83.28	47.29	105.80	100.00	100.00	100.00	100.00
Domestic water price	Zero	100.00	102.12	100.00	100.00	100.61	100.00	100.00	100.00	100.20	100.00	100.00	100.00
	2*base	100.00	97.89	100.00	100.00	99.39	100.00	100.00	100.00	99.33	100.00	100.00	100.00
	3*base	100.00	95.79	100.00	100.00	98.78	100.00	100.00	100.00	98.52	100.00	100.00	100.00
Industrial water price	Zero	100.00	100.00	113.33	100.00	106.46	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	2*base	100.00	100.00	86.67	100.00	93.54	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Coffee/Pepper price	In 1998	135.01	100.00	100.00	100.00	105.33	100.23	99.54	99.60	99.97	100.66	100.00	100.00
	In 2001	72.08	100.00	100.00	101.41	95.85	92.33	88.16	86.39	100.00	100.00	100.00	100.00

Note: [a]Upper bounds were relaxed for the high flow scenario. [b]Field application efficiency, baseline: 0.7; total withdrawals include pumping. withdr = withdrawals; dom = domestic.

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 the plant. When field application efficiency is reduced to 0.5, total basin profits barely decline. Profits from irrigated agriculture drop by 3 percent, and irrigation withdrawals increase by 14 percent. As a result, hydropower profits decline slightly by 1 percent. On the other hand, if the irrigation efficiency is increased to 0.9, profits from irrigation increase to 102 percent of baseline levels, irrigation withdrawals drop to 92 percent of baseline levels, and irrigation areas increase to 104 percent of initial values. Other sectors remain basically unaffected.

As discussed above, the irrigation supply cost used here is a broader concept, incorporating actual costs as well as labor cost for irrigation. In the baseline, an average fee by crop is used for consumptive water use. The fee is set at 50 percent of survey levels , to allow for positive profits even in those basin areas where application levels are high. The pumping fee is set at US$0.07/m^3. For the sensitivity analysis, the irrigation fees are set alternatively to zero, to the total water-application level, and then to the level of survey observations for applied (prior to field application efficiency) water. At a water price of zero (including all the components specified above), irrigation profits increase to 123 percent of baseline levels, and total profits by 4 percent. Irrigation withdrawals increase to the very high level of 331 percent over baseline withdrawals, and irrigated area increases to 116 percent of the baseline area. The industrial and domestic sectors compensate for slight declines in surface withdrawals, due to the increased competition with irrigation withdrawals, by means of increased groundwater abstractions. At the "full" irrigation cost, profits from irrigated agriculture decline to 89 percent of baseline levels, and irrigation withdrawals drop by more than half. As the pumping costs increase by a relatively smaller amount, pumping increases slightly. Finally, irrigated area decreases by 17 percent. Other sectors are not affected. Increases and reductions in the domestic water price lead to small shifts in domestic profits and a very small decline in domestic surface-water withdrawals. In the industrial sector, withdrawal levels are unchanged under a doubling of the water supply cost, but profits decline to 87 percent of baseline levels.

Several major agricultural commodities experienced sharp declines in Vietnam and elsewhere over the past few years. Table 10 shows the change in farm-gate prices for selected irrigated agricultural commodities in the Dong Nai river basin. Although the rice price in Vietnam has dropped significantly in the Mekong delta, prices in the Dong Nai basin remained stable due to the relatively lower quantity and higher quality of rice produced. To see the impact of recent price changes on farmer incomes, alternative simulations are carried out for the 1998 and 2001 coffee and pepper prices. Converted to US dollars, the prices implemented in the model are US$1,033/mt, US$647/mt, and US$372/mt, for 1998, survey (1999/2000), and 2001, respectively, for coffee—a drop by a factor of 2.7 over 3 years—and US$4,590/mt, US$3,434/mt, and US$1,149/mt for pepper, a drop by a factor of 4 over the period. The results of the alternative simulations are shown in table 9. If the 1998 coffee and pepper prices would prevail, irrigation profits would increase to 135 percent over baseline levels, and total basin profits by 5 percent. Coffee area increases by 6,000 hectares, whereas pepper has already reached the upper bound in the baseline. In the case of 2001 coffee and pepper prices, profits from irrigated agriculture dropped to 72 percent of baseline levels, and total profits declined to 96 percent. Irrigated area shrank by 8 percent, and irrigation withdrawals by 12 percent, supporting a slight increase in hydropower production. Coffee area sharply declined by 60 percent to 42,000

Table 10. Price changes for selected irrigated agricultural commodities, Dong Nai basin (VND/kg).

	1997	1998	1999	Survey*	2001
Pepper		60,000	33,000	48,014	17,000
Coffee	22,000	13,500	9,000	9,051	5,500
Rice	1,650	1,650	1,650	1,530	1,650

Note: Survey was implemented for April 1999–April 2000.
Source: Data for 1997–1999 and 2001 provided by Sub-NIAPP.

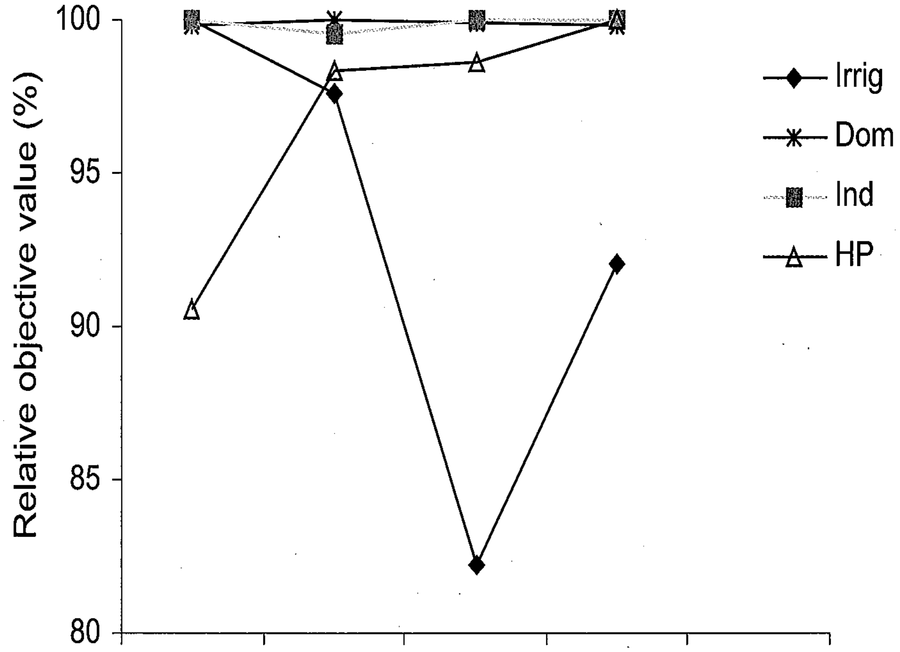
hectares, whereas area planted to pepper declined only slightly by 147 hectare or 3 percent. This differing reaction to changes in crop prices was due to the larger profit margin for pepper (see also table 8).

Trade-off Analysis

In order to show potential trade-offs among the competing objectives of irrigation, domestic and industrial uses, and hydropower production, a trade-off analysis is carried out based on the weighting method. This method is implemented here by running a separate scenario for each primary objective, that is, for irrigation, domestic benefits, industrial profits and hydropower profits. The primary objective in this case is multiplied by a factor of 100 while the other objective functions remain unchanged. These scenarios are run for a low-flow scenario (90% probability level) to better demonstrate potential trade-offs. Overall profits from water uses decline under each of these alternative runs, albeit by very small amounts. The largest decline occurs for the hydropower scenario, but equals just 1 percent of total profits. Scenario outcomes are shown in figure 13. The result from the primary objective function in each scenario was scaled to 100. The curves for the individual objective functions show how they fare under the various primary objectives listed on the x-axis.

Clearly, the largest trade-off occurs for irrigation. When domestic uses are the primary objective, irrigation profits decline by 2.4 percent; under industrial preference, irrigation incomes drop by 18 percent, and when hydropower production is favored, irrigation profits decline by 8 percent. Irrigation is most affected by preferential treatment of other sectors due to the relatively lower value of water in agriculture and the large quantities of water involved in irrigated agriculture. There are also slight trade-offs between hydropower production and other sectors. When irrigation is the primary objective, hydropower profits decline to 91 percent of the maximum potential level; when domestic or industrial uses are favored, profits drop by 2 percent. The decline in hydropower production is due to the increased water depletion for irrigated agriculture. There are only very minor trade-offs for domestic uses. Industrial water use is the least affected by trade-offs from other sectors, due to the large marginal value of water in the sector.

Figure 13. Trade-off analysis among competing objectives.



Note: Inflows and effective rainfall at 90% probability level.

Water Allocation and Use by 2010

Model Data

By 2010, the following reservoirs are expected to be constructed: Can Don, Sroc Phu Mieng, and Phuoc Hoa on the Be river, Dai Ninh, Dong Nai 3, and Dong Nai 4 on the Dong Nai main stream, and Song Luy reservoir on the Luy river in the coastal area. This will increase hydropower capacity to 2,171 megawatts and annual power production is expected to increase to 8,507 gigawatt hours. Total planned investment costs are 1,672 million US dollars.[16]

Phuoc Hoa will release a maximum of 50 m^3/sec to the Dau Tieng reservoir on the Sai Gon river and a minimum of 14 m^3/sec to the Be river, and Dai Ninh will release a maximum of 20 m^3/sec to the Luy river. Minimum in-stream flows by 2010 will increase to 110 m^3/sec at Binh An on the Dong Nai river and to 30 m^3/sec at Ben Than on the Sai Gon river.

According to SIWRP, the government agency in charge of irrigation planning in southern Vietnam, irrigated area in the basin will increase by more than 500,000 hectares by 2010—at a very high rate of increase of 5.1 percent per year—to reach 1,350,726 hectares. According to the estimates by Sub-NIAPP, the agency in charge of land-use planning in southern Vietnam, the area will increase to approximately 1,329,074 hectares. For projection purposes, in a first approach, the Sub-NIAPP cropping pattern has been included into the model proportionately to the 1999/2000 area. Exceptions were made for specific large-scale projects, like Phuoc Hoa irrigation area (6,300 ha in Binh Duong/Binh Phuoc, 14,400 ha in Tay Ninh, and 31,050 ha in Long An), and the Song Luy project in the Binh Thuan Province. In the next phase, irrigated area by irrigation zone to be finalized by SIWRP will be used. Sub-NIAPP expects an irrigated cotton area of approximately 21,000 hectares by 2010. However, as no survey observations on cotton were available, the crop has so far not been included in the analysis. Sub-NIAPP also projects large increases for irrigated perennial crops: fruit trees, by 59,000 hectares; irrigated coffee, by 36,000 hectares; and pepper, by 29,000 hectares. Paddy areas in the summer-autumn and rainy seasons are also expected to increase by approximately 100,000 hectares, whereas dry-season rice is projected to slightly decline, by 3,300 hectares (see also figure 2). Irrigation fees for surface withdrawals were doubled compared to the baseline, and for groundwater pumping they were increased to US$0.09/$m^3$. All other parameters were left unchanged.

Several provinces in the Dong Nai river basin have plans for major water-supply capacity expansion by 2010. For example, HCMC plans to increase its capacity from 930,000 m^3/day in 2000 to 2.2 million m^3/day in 2010. Other provinces with major increases include Tay Ninh from 9,300 m^3/day in 2000 to 28,800 m^3/day in 2010, and Ba Ria Vung Tau from 62,600 m^3/day in 2000 to 171,900 m^3/day in 2010. From data available for several provinces, total expansion is estimated at about 1.5 million m^3/day. However, only a share of capacity will translate into deliveries, and part of these deliveries will be for industrial water supply. For population projections, the growth rates in the basin for domestic and rural areas during 1995–2000 were applied to the 2000–2010 period (see table 11), with an average growth of 3.59 percent per year, largely due to very high urban growth. The projected 2010 basin population reaches 19 million people, 59 percent of whom will live in urban areas, up from 49 percent in 2000. Whereas water demand in 1999 was based on supply capacity, complemented with minimum standards of 40–50 l/cap/day for

Table 11. Urban and rural growth in the DNRB, 1995-2000.

	Urban growth 1995-2000 (%/yr.)	Rural growth
HCMC	4.69	-5.98
Ninh Thuan	3.81	1.50
Binh Phuoc	5.21	5.21
Tay Ninh	5.05	0.95
Binh Duong	17.06	-1.35
Dong Nai	3.18	1.54
Binh Thuan	7.59	0.45
Ba Ria Vung Tau	7.03	0.62
Lam Dong	5.47	3.03
Long An	4.86	0.49
Dak Lak	na	5.77

Note: na = not applicable.
Source: Calculated based on Statistical Yearbook 2000. Statistical publishing house, Hanoi, 2001.

[16]These costs include the irrigation infrastructure for Phuoc Hoa and Song Luy.

districts without public water supply, water demand for 2010 is calculated based on supply standards: 60 l/cap/day for rural areas and 120 l/cap/day for urban areas. Total estimated demand reaches 666 million m^3 up from 336 million m^3 in 1999/2000. Income growth is projected at 5 percent per year and water prices are projected to double over the time frame.

For 2010, total net industrial water demand is estimated at 491 million m^3, at an annual growth rate of 5 percent per year. Industrial water delivery costs increase by 50 percent over the period, averaging US$0.39/$m^3$ by 2010. It is assumed that the share of surface water and groundwater deliveries remains unchanged.

Analysis

For the 2010 scenario, total off-stream water withdrawals are estimated at 4,647 million m^3. Domestic surface withdrawals increase by 89 percent to reach 1,023 million m^3, industrial withdrawals by 72 percent to reach 1,052 million m^3, and irrigation surface withdrawals by 11 percent to reach 2,572 million m^3. Minimum flow requirements to ensure withdrawals at the major domestic supply offtake points increase by 27 percent to reach 4,415 million m^3. Moreover, total groundwater abstractions increase rapidly to 854 million m^3, an increase of 201 percent over baseline pumping. Irrigation pumping increases by 382 percent to reach 496 million m^3; domestic pumping by 104 percent to reach 322 million m^3; and industrial pumping by 50 percent to reach 35 million m^3. Total groundwater abstracted represents only 8.4 percent of estimated total shallow groundwater capacity as yet. However, in the key dry-season months of January to March, an average of 37 percent of capacity is exploited. Moreover, in several provinces, the share is much higher and even reaches 100 percent in January and March in the Binh Phuoc Province, a key grower of perennial crops relying on groundwater (see table 12). Total hydropower produced amounts to 9,541 gigawatt hours, an increase by 81 percent over 1999/2000 production levels.

Figure 14 shows the discharge and demand situation under the 2010 alternative scenario. Discharge during the dry-season months of January to April, in fact, increased by an average of 150 million m^3 or 57 m^3/sec compared to the baseline scenario. The shift of additional flow into the dry season is due to the additional storage of 2,901 million m^3 to be constructed by 2010. However, although the 2010 scenario envisions large-scale investment into additional reservoir storage, the

Table 12. Share of shallow groundwater exploited, 2010 scenario (in %).

	January	February	March
Binh Duong	48	57	49
Binh Phuoc	100	98	100
BRVT	34	36	84
Dong Nai	22	36	32
HCMC	37	40	36
Long An	42	53	59
Lam Dong	33	67	10

gap between the demand and supply curves is reduced to half the baseline level for the month of February, and the basin is moving into a semi-closed state. Moreover, under the 2010 scenario, demands would not be met from natural flows (no storage) during three consecutive months (February–April, by between 214 million m^3 and 406 million m^3).

A significant result of this preliminary 2010 scenario is that the projected cropping area of 1,307,774 hectares cannot be achieved. Instead, the area is reduced by 139,129 hectares or 11 percent (see table 13). The major decline in percentage terms occurs for sugarcane, followed by rice and, in absolute terms, for rice, followed by coffee. If the complete projected cropping area had been implemented, total surface withdrawals could have increased by a further 1.8 BCM, an increase of 72 percent. However, most of this would be demanded in the summer-autumn and rainy seasons. Local water shortages in selected areas during the dry season, and particularly the doubling of the irrigation fees for surface areas and the increase of groundwater pumping costs from US$0.07/$m^3$ to US$0.09/$m^3$, compared to the baseline parameters, are the lead causes for the underachievement in irrigation area, making several commodities unprofitable for farmers.

Figure 14. Flows and withdrawals, 2010 scenario.

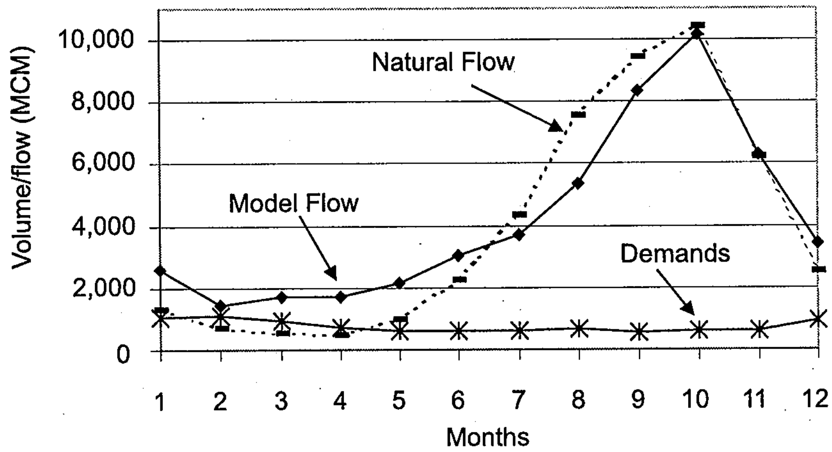


Table 13. Irrigated area, projected 2010 and change in 2010 scenario result.

	Area, projected 2010 (ha)	Change in area, model (ha)	Change (%)
Bean	26,270	4,378	17
Coffee	201,136	-11,157	-6
Fruit trees	103,809	13,084	13
Maize	35,749	7,101	20
Paddy	670,620	-198,866	-30
Peanut	86,338	16,616	19
Pepper	39,465	7,893	20
Sugarcane	13,350	-4,385	-33
Tobacco	17,161	3,432	20
Vegetables	113,876	22,775	20
Total	1,307,774	-139,129	-11

Table 14 shows the net profit situation in 2010, compared with the baseline result. Total basin profits increase by 50 percent. Irrigation profits increase steeply, by a factor of 2.7; profits from water use in industry jump by 53 percent and for hydropower by 66 percent. Domestic net benefits, on the other hand, decline, despite a large increase in the withdrawal capacity. This is due to the doubling of supply costs incorporated for domestic uses. Thus, by 2010,

Table 14. Profits and withdrawals, 2010 scenario, compared with baseline.

	2010	1999/2000	Change
Profit/Benefit (M US$)	3,228	2,123	52
Irrigation	886	323	174
Domestic	508	615	-17
Industry	1,576	1,030	53
Hydropower	258	156	66
Irrigated area ('000 ha)	1,169	753	55
Withdrawals (MCM)			
Agricultural water withdrawal	3,068	2,414	27
- pumping	496	103	382
Domestic water withdrawal	1,345	700	92
- pumping	322	158	104
Industrial water withdrawal	1,087	635	71
- pumping	35	23	50

the water demands in the basin can still be met without major competition among water-using sectors and the total benefit for the basin economy is set to increase. However, several issues need to be further studied, including the costs of planned investments, as well as the likelihood of planned investments, for example, in the irrigation sector.

Conclusions

The paper has 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 in-stream 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 inter-sectoral and multi-province analyses of water allocation and use with the objective of determining trade-offs 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 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. At the same time, minimum in-stream flows are guaranteed. However, efficient water allocation is not necessarily congruent with actual water allocation and use in the Dong Nai basin. Thus, baseline profits might be larger than actual profits in the basin, and the behavior simulated in the model under alternative scenarios will likely not be replicated in the same form in the real world.

Based on the preliminary results from the modeling framework, a series of general conclusions can be drawn for the DNRB: trade-offs in water uses between the various water users and uses in the basin do exist; however, at the current stage of agricultural and economic development they are rather small and are largely confined to the dry season or low-flow conditions. The DNRB today can be characterized as an open basin, that is, sufficient water resources are available throughout the year for continued agricultural and economic development. However, as the 2010 scenario shows, the basin does approach a semi-closed state, where demand in the dry season cannot be fully met. Moreover, a trade-off analysis for the baseline year has shown that overall trade-offs in the baseline are relatively low, but that the irrigation sector will be most adversely affected if other sectors are favored in development, due to the relatively lower value of water in agriculture and the large quantities of water involved in irrigated agriculture.

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[17]The projected cost for the North-East South Region is VND 781 billion; an exchange rate of US$1.00 = VND 15,000 has been applied.

The choice of cropping pattern and crop alone could save large amounts of water resources in the dry season, as the irrigation water applied and the water productivity vary substantially by crop. Paddy, for example, in general, has a relatively low productivity of water and is one of the least profitable crops in the basin. If quantity-based water fees or higher fees, in general, were to be introduced in the future, careful analysis will be necessary as, in many basin areas, profits from irrigation can be wiped out even at low water-supply costs. However, withdrawals can be very large if no fees are set. According to current cropping plans for 2010, rice area in the basin is set to continue to increase. If plans to increase the irrigation service fee will also be implemented, continued improvements in the quality of rice products would need to be achieved for farmers to obtain sufficient income from rice production.

Model results favor some shifts away from low-value rice crops and towards more fruit trees, maize, peanut and vegetable crops. Continued liberalization of the agriculture sector, combined with improved access by farmers to information, careful market analysis, and improved post-harvest technologies are all strategies that will eventually help save some of the water currently in low-value uses. However, this strategy can only be applied selectively in certain basin areas to avoid market saturation. Model outcomes also show the large impact that increases in irrigation efficiency can have on water savings in agriculture. However, it needs to be further studied if the projected cost for canal lining for 1995–2002 of US$52[17] million in the basin can be justified by those savings, as water is still relatively abundant in the basin. The simulation of alternative prices for pepper and coffee shows their large impact on the irrigated basin economy over the last few years. Stabilizing and increasing farm-gate 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.

Although no closed groundwater balance could be included into the model due to lack of data, the partial analysis shows that groundwater overdrafting could become a reality in the DNRB in the coming decades. This is largely due to the expansion plans for groundwater-irrigated perennial crops, like coffee, fruit trees and pepper. Canal lining might further contribute to declining availability of shallow groundwater in groundwater-irrigated areas, particularly downstream of the Dau Tieng reservoir. Finally, continued and expanded industrial and domestic reliance on groundwater can lower groundwater tables in local areas. However, further analysis will be needed to obtain a better understanding of the existing capacity, and of interactions among groundwater and surface-water sources, before final conclusions can be drawn.

An alternative 2010 scenario shows that basin-water demands can still be met by 2010, although the gap between supply and demand is increasingly closing. Meeting demands hinges on several issues, particularly the implementation of planned reservoir projects—to increase supply—and also on the actual realization of the large planned increases in irrigation development, which would significantly increase demand.

The provinces, and the large number of water-related agencies involved in basin-water allocation, need to cooperate very closely to achieve the benefits indicated from model results. The optimal utilization of the basin-water resources through allocation of water to the highest-valued uses requires extensive information about the quantity and value of DNRB water over space and time. Although the newly established basin-planning management council cannot attempt to play the role of a "close-to-omniscient" decision maker in the basin with "perfect" knowledge about the basin-water resources—the information and transaction costs would be prohibitive—it should strive to go beyond its likely initial focus on only planning, to achieve close collaboration among the basin provinces and agencies so as to increase overall basin benefits while protecting the vulnerable water resource from pollution, particularly in the lower basin.

The next step for the analysis will be the discussion of final parameters and preliminary results of the baseline, as well as a further check on the planned investments up to 2010 and possibly 2020 together with the policymakers and other stakeholders in the basin. Moreover, the model will be calibrated so that the baseline reflects the actual water-allocation and use-situation during 1999/2000 more accurately (positive modeling). Furthermore, alternative specifications of irrigation service fees will be analyzed, as will the benefits and costs of incorporating some of the additional infrastructure projects in the basin. Based on the final model structure and parameters, institutions based on the separate institutional analysis as well as parameters from the national-level study on taxation and subsidies in agriculture and irrigation will be incorporated into the modeling framework. If time permits, a linkage will be made with the SIWRP VRSAP (Vietnam river system and plains) model to allow for a more in-depth analysis of water-quality implications of model results. Finally, the modeling framework will be further employed to explore the impacts of alternative institutions and water-allocation mechanisms on the basin-water economy.

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