



## Research Article

# Assessment of Secure Exploitation Reserve of Groundwater Source in Camau Peninsula, Vietnam

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### Abstract

In the Camau Peninsula, groundwater is an important freshwater source, which has been being exploited and used widely, playing a very important role in the progress of socio-economic development in the localities in the Peninsula. However, due to the local natural characteristics, the law of distribution of good quality water is complicated by the presence of saltwater layers in the aquifers, causing many

difficulties in the exploitation and usage of the fresh groundwater. The paper uses data collected from the studies of specialized agencies and localities that have been implemented so far. The study results show that potential groundwater exploitation reserve is 11,340,100m<sup>3</sup>/day and secure exploitable groundwater reserve is 741,500m<sup>3</sup>/day for the entire Camau Peninsula.

**Keywords:** Camau Peninsula; Hydrogeology; Groundwater; Potential exploitable groundwater reserve; Secure exploitable groundwater reserve

## 1. Introduction

Secure Exploitable Groundwater reserves of a groundwater basin or aquifer system is defined as the amount of water that can be exploited from it without producing an undesired effect [1, 2] secure exploitable groundwater reserves yields limit to the quantity of water which can be exploited regularly and permanently without dangerous depletion of the storage reserve. He was also the first to recognize the need to reserve a fraction of the recharge for the benefit of the surface waters and related ecosystems [3]. realized that all groundwater is formed by continuously moving through a porous environment, from the recharge zone to the discharge area. He recognized that in its pristine condition, the aquifer was in an approximate dynamic equilibrium. Until groundwater is extracted (drained by pumps), the aquifers will form a new balance by: increasing the natural recharge capacity; reduce natural emissions; loss of storage in aquifers; or combine them.

Hydrogeological study for an area in Viet Nam, determination of groundwater exploitable reserve is a usual obligatory requirement. Depending on concrete investigation stage or requirement of a project, a grade of reserve will be determined. As for detailed investigation projects (groundwater exploration, exploitation license), an exploitable groundwater reserve must be determined for well fields. As for general groundwater investigation or preliminary groundwater investigation projects, just potential exploitable groundwater reserve determined with balance method is required. In trend of sustainable

development, secure exploitable groundwater reserve is oriented. It is essential information for groundwater resources planners and managers. Potential exploitable groundwater reserve is a common question in hydrogeological study. There are methods for its determination. However, once this groundwater exploitable reserve is totally exploited, the groundwater resources will be degraded. In natural conditions such as in Camau peninsula, groundwater exploitation usually induces salinity intrusion (vertical and horizontal). Therefore, how much groundwater can be exploited to assure sustainable development purpose? This question is related to secure groundwater exploitable reserve. As a result, a maximal quantity of groundwater must be determined such that the sustainable development purpose be assured. In this paper, question of sustainable groundwater exploitation is approached by determination of secure exploitable groundwater reserve with groundwater flow modeling in combination with groundwater sustainability index [4].

This index is calculated with formula:  $I = \frac{\text{Total exploited amount}}{\text{Total recharge amount}} \times 100\%$

$I < 90\%$ : Sustainable;  $I = 90 \div 100\%$ : Less sustainable;  $I \geq 100$ : Unsustainable; *Total exploited amount*: is calculated after data of actual groundwater exploitation status; *Total recharge amount (natural)*: is determined with digital modeling.

In Camau peninsula, main groundwater recharge is dynamic reserve generated from horizontal and vertical filtration, including both fresh and saline water modeling method is a most suitable mathematical tool for calculating total annual fresh groundwater recharge in a concrete region.

Total recharge amount is calculated as total flow in amount or total flow out amount in groundwater balance. Therefore, to determine secure exploitable reserve in Camau peninsula the author will rely on total

flow in amount based on groundwater balance of the groundwater model for fresh groundwater area, not including filtration flow in from saline groundwater area (Figure 1).

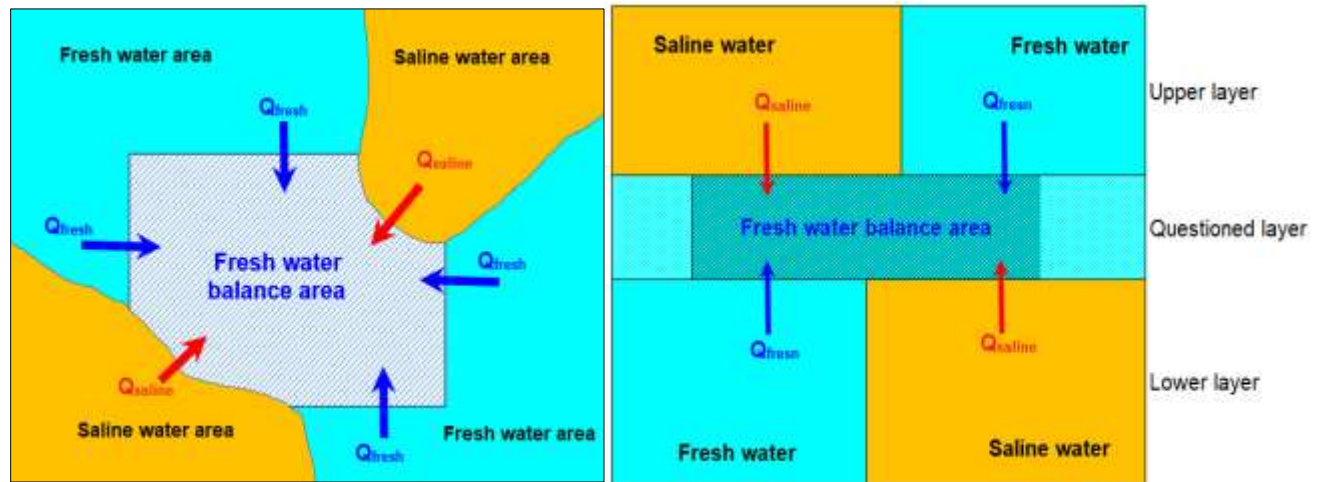


Figure 1: Scheme of flows to balanced area (zone budget) horizontal (right) and vertical (left).

Used data are original data of previous studies of the former Department of Geology and Minerals and recent collected data. Data are summarized and processed in accordance with hydrogeological

stratification orientation [5]. Information in this paper (calculation results, digital model and maps) are data recently implemented by group authors in the theme KC08.08/16-20.

#	Aquifers	Areas (km <sup>2</sup> )	Areas by regions (km <sup>2</sup> )							
			A	B1	B2	B3	C1	C2	D	E
1	qh	8,052	3,826	1,482	1,558	181	183	18	602	201
2	qp <sub>3</sub>	14,545	4,332	1,482	1,923	968	2,177	1,025	1,086	1,553
3	qp <sub>2-3</sub>	16,564	4,332	1,482	2,083	1,132	2,177	1,053	1,254	3,051
4	qp <sub>1</sub>	16,667	4,332	1,482	2,082	1,132	2,177	1,052	1,359	3,052
5	n <sub>2</sub> <sup>2</sup>	16,092	4,332	1,482	2,082	1,132	1,639	1,015	1,358	3,051
6	n <sub>2</sub> <sup>1</sup>	15,580	4,332	1,482	2,082	1,132	1,448	688	1,365	3,051
7	n <sub>1</sub> <sup>3</sup>	14,111	4,149	1,482	2,082	1,132	572	286	1,357	3,051

Table 1: Horizontal distribution of aquifers.

#	Aquifers	Top depth (m)			Bottom depth (m)			Thickness (m)		
		From	To	Average	From	To	Average	From	To	Average
1	qh	0.0	61.0	19.6	8.0	75.0	30.8	0.6	65.0	11.3
2	qp <sub>3</sub>	20.0	94.5	46.3	29.0	162.0	71.7	1.9	122.4	25.6
3	qp <sub>2-3</sub>	44.0	162.0	85.1	62.2	207.0	127.2	2.0	109.5	42.1
4	qp <sub>1</sub>	85.5	226.0	147.0	108.0	287.2	186.9	3.0	110.2	39.9
5	n <sub>2</sub> <sup>2</sup>	130.0	310.6	210.6	144.0	334.0	256.9	3.0	133.0	46.3
6	n <sub>2</sub> <sup>1</sup>	149.0	363.3	283.4	180.0	408.7	328.6	10.0	139.0	45.3
7	n <sub>1</sub> <sup>3</sup>	285.4	508.0	378.0	313.5	602.0	442.3	6.5	129.0	64.2

Table 2: Vertical distribution of aquifers.

2. Characteristics of Aquifers

In Camau peninsula there are 7 granular aquifers, being: Holocene (qh), Upper Pleistocene (qp<sub>3</sub>), Middle-Upper Pleistocene (qp<sub>2-3</sub>), Lower Pleistocene (qp<sub>1</sub>), Middle Pliocene (n<sub>2</sub><sup>2</sup>), Lower Pliocene (n<sub>2</sub><sup>1</sup>) and

Upper Miocene (n<sub>1</sub><sup>3</sup>). Spatial distribution of aquifers is presented in (Tables 1 and 2). Locations of fresh saline interfaces are edited based on studied results of Nguyen Huy Dung [5] and updated with recent studied results (Figures 2 to 4).

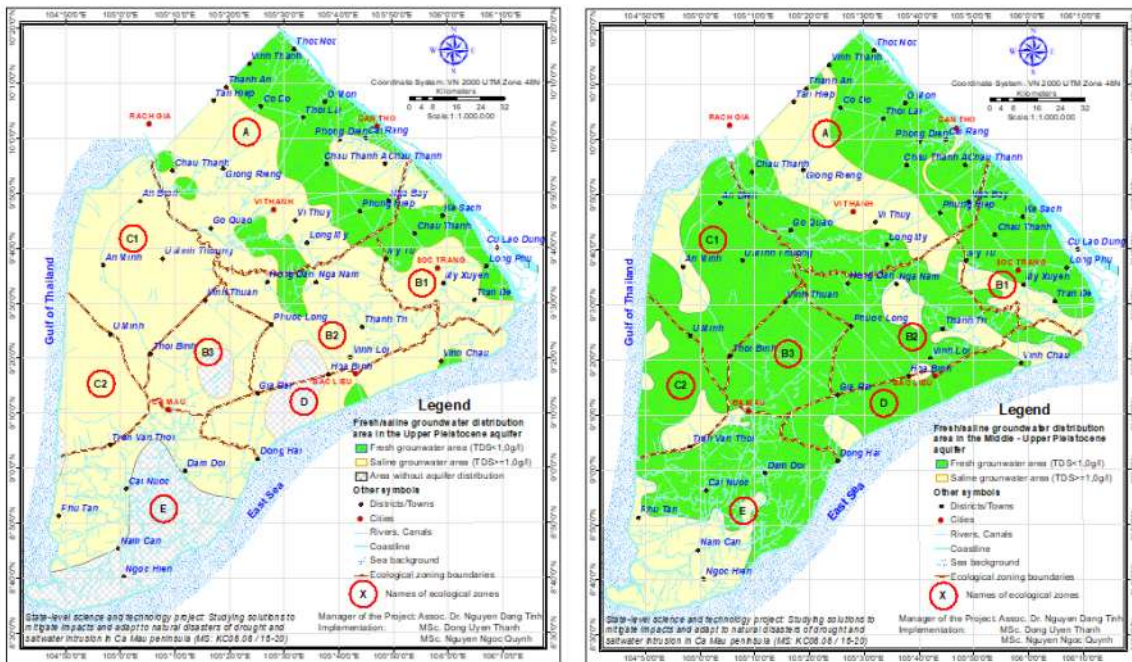


Figure 2: Fresh and saline water distributions in Upper Pleistocene and Middle-Upper Pleistocene aquifers.

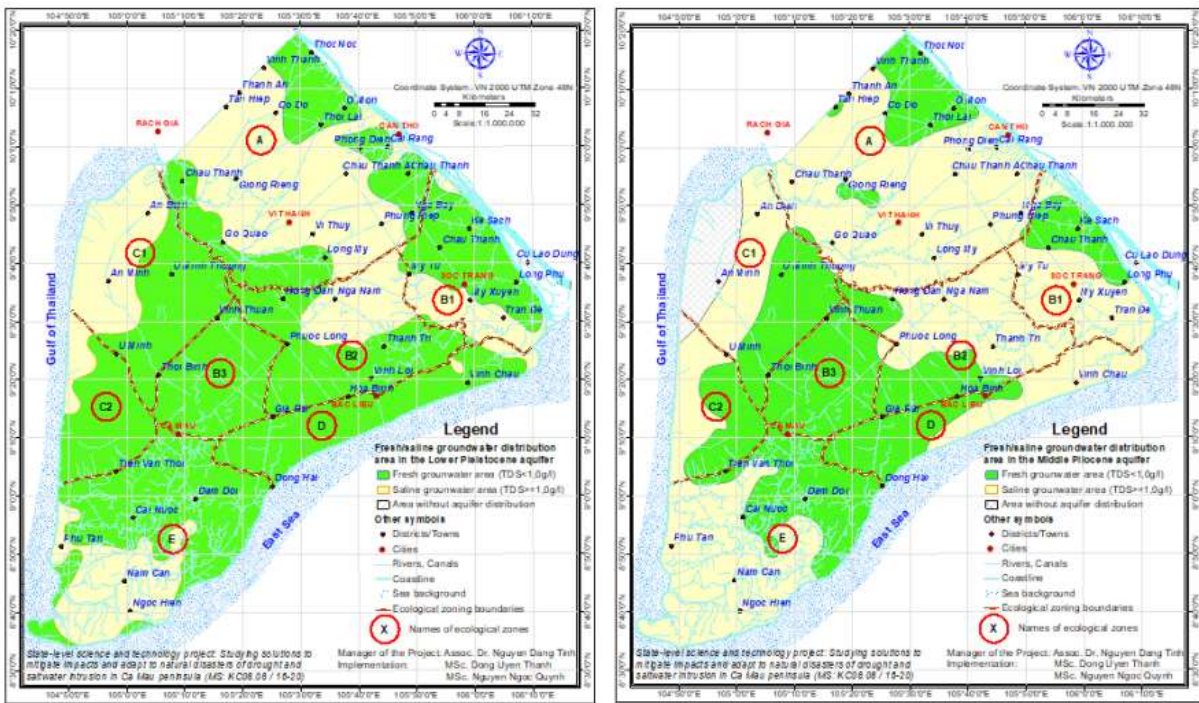


Figure 3: Fresh and saline water distributions in Lower Pleistocene and Middle Pliocene aquifers.

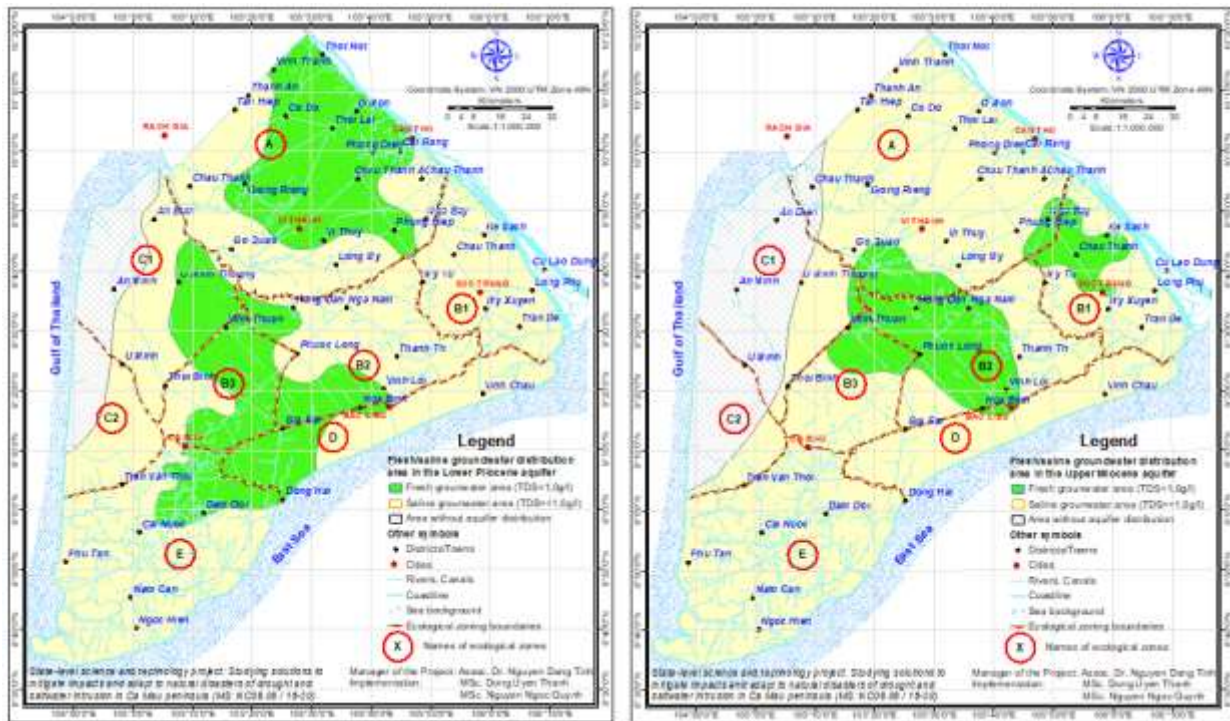


Figure 4: Fresh and saline water distributions in Lower Pliocene and Upper Miocene aquifers.

### 3. Construction Grondwater Flow Model for Camau Peninsula Area

#### 3.1 Briefly about theory of groundwater flow model

**3.1.1 The basic equation:** Groundwater is a liquid mineral, so its reserve as well as regime are constantly change. This change is necessary to quantify and correctly describe to serve for problems of reserve calculation, flow, and contaminant dispersion. Most importantly, it supports groundwater resources management and planning. Overall changes of groundwater heads are described by a unique partial differential equation as follows:

$$\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t} \quad (1)$$

- $K_{xx}, K_{yy}, K_{zz}$  : Hydraulic conductivity in x, y and z directions. Z is vertical direction
- h: Head at location (x,y,z) at time point t
- W: Underground flow modulus, or source, sink of groundwater at location (x,y,z) at time point t.  $W = W(x,y,z,t)$  is an function of time and space (x,y,z)
- $S_s$  : Specific storage
- $S_s = S_s(x,y,z)$ ,  $K_{xx} = K_{xx}(x,y,z)$ ,  $K_{yy} = K_{yy}(x,y,z)$ ,  $K_{zz} = K_{zz}(x,y,z)$  are functions of spatial locations x,y,z

Equation (1) describes head regime under conditions of heterogeneous and anisotropic medium. In combination with boundary conditions and initial conditions of aquifers, it constitutes a mathematical model of groundwater flow.

**3.1.2 Implementation procedure:** In combination of specialized hydrogeological theories with mentioned modeling theory, implementation procedure for construction of a groundwater flow model is as follows:

- Data preparation: Schematizing hydrogeological conditions of the groundwater system. Data collection, data processing to match them with the calculating scheme.
- Data Input: Inputting spatial data (attributable properties of layers), initial conditions, timely data (various boundaries)
- Run and Calibration of the model: Choosing time step and running the model for its calibrating. After successfully calibration, next running the model to solve the required hydrogeological problem.

**3.1.3 Assessment of simulation quality:** Results of the adverse solved problem is required for qualitative and quantitative assessment. After National Research Council (1990), the last purpose of the calibration problem is minimizing error values. There are 3 kinds of errors for assessing differences between monitored and modeled heads, being: i) Mean error (ME), ii) Maximal average error (MAE), iii) Root Mean square (RMS) or standard deviation. MAE and RMS are suitable criteria for assessing quality of the model.

#### 3.2 Groundwater flow model of the Camau peninsula area

The groundwater flow model of Camau peninsula area was constructed with GMS 10.2 software and set of collected data and monitoring data of the groundwater regime in Camau peninsula area.

**3.2.1 Schematization of the porous media:** Based on natural conditions and hydrogeological setting of Camau peninsula, the hydrogeological problem will be solved with a scheme of 15 layers simulating 7 poorly productive geological formations, 7 aquifers and 1 bedrock layer.

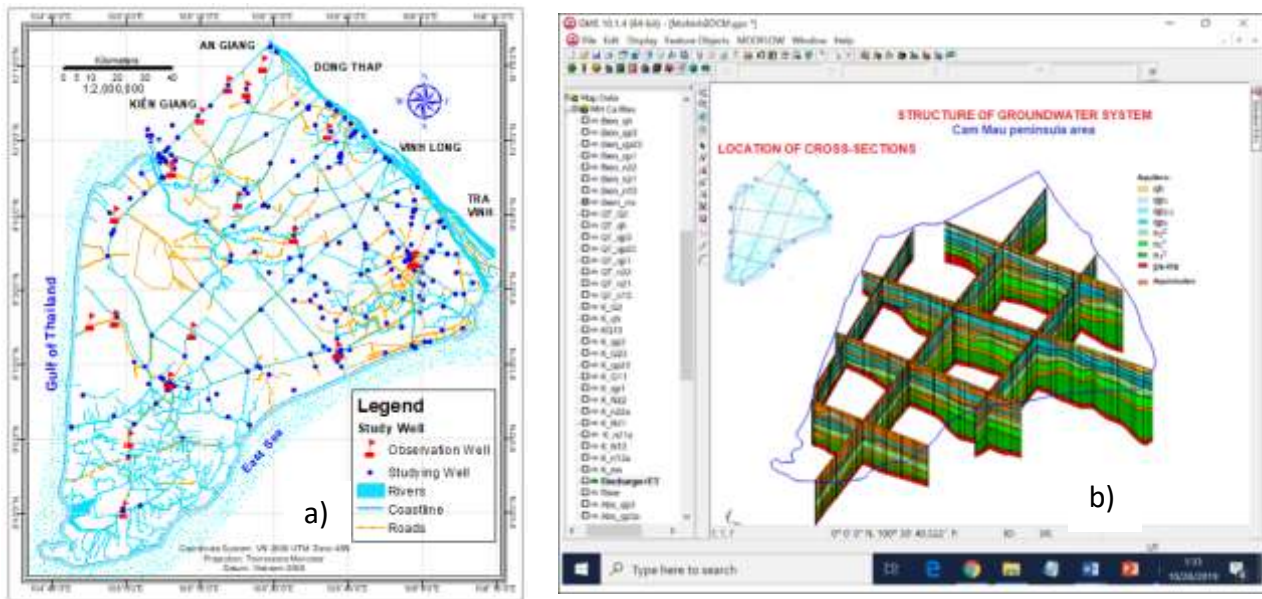
**3.2.2 Data input:** Coverage are as follows:

- 01 coverage of Recharge – Evapotranspiration (ET) rate: after meteorological data available in concerned provinces;
- 01 coverage of River Head: Head values on boundaries after data of hydrological stations;
- 15 coverage of attributabilities: Horizontal hydraulic conductivity ( $k_h$ ), vertical hydraulic

conductivity ( $k_v$ ), specific storage ( $\mu^*$ ), storage yield ( $\mu$ ): after pumping data at 306 wells for 15 simulated layers;

- 08 coverage simulating distributions of layers;
- 07 coverage of groundwater abstraction: After exploitation data in the concerned provinces for 7 aquifers (no abstraction from layer 15);
- 07 coverage of monitored heads: Monitoring data at National Groundwater Monitoring Stations for 7 aquifers (no monitoring well in layer 15);

(Figure 5) shows coverage and locations of study wells of lithology and attributable parameters.



**Figure 5:** (a) Range of the model and locations of study wells; (b) Spatial distributions of aquifers and coverage.

**3.2.3 Simulation time:** 36 months (from January 2015 to December 2017).

**3.2.4 Results of model calibration:** The groundwater flow model of the Camau peninsula uses real

monitoring data at 18 locations with 62 monitoring wells for calibration. The resulted RMS for the entire model is in range of  $\pm 0.5m$ .

**4. Results and Discussion**

**4.1 Potential groundwater exploitable reserve**

The potential groundwater exploitable reserve is calculated by balance method with formula:  $Q_{kt} = Q_{dl} + Q_{dh} + Q_d$  (2) Where:  $Q_{dl}$  is Static gravitational reserve;  $Q_{dh}$  is static elastic reserve;  $Q_d$  is dynamic reserve and  $Q_{ct}$  is induced reserve. Dynamic reserve  $Q_d$  is determined from flow budget by the

groundwater flow model, including induced reserve. The potential groundwater exploitable reserve is evaluated for 6 potential aquifers, being:  $qp_3$ ,  $qp_{2-3}$ ,  $qp_1$ ,  $n_2^2$ ,  $n_2^1$  and  $n_1^3$ . Aquifer  $qh$  and aquifer  $ps - ms$  (bedrock) have limited distribution range, small thickness, poor productivity, so no calculation made for them.

Aquifer	Potential fresh groundwater exploitable reserve (m <sup>3</sup> /day)								Total (m <sup>3</sup> /day)
	A	B1	B2	B3	C1	C2	D	E	
<b>qp<sub>3</sub></b>	433,679	170,785	36,575	0	0	0	14,571	0	655,611
<b>qp<sub>2-3</sub></b>	887,558	387,348	532,591	322,987	544,772	242,478	329,285	529,664	3,776,684
<b>qp<sub>1</sub></b>	439,591	279,629	394,524	313,125	311,600	248,521	403,621	627,469	3,018,079
<b>n<sub>2</sub><sup>2</sup></b>	198,225	115,277	202,120	321,117	237,426	154,507	209,349	394,273	1,832,295
<b>n<sub>2</sub><sup>1</sup></b>	568,309	703	155,106	201,224	124,264	0	150,957	143,250	1,343,814
<b>n<sub>1</sub><sup>3</sup></b>	146,056	127,137	334,778	93,914	702	0	11,033	0	713,620
<b>Total</b>	2,673,420	1,080,879	1,655,694	1,252,367	1,218,764	645,506	1,118,816	1,694,656	11,340,102

**Table3:** Potential groundwater exploitable reserve.

Aquifers	Dynamic reserves of ecological regions (m <sup>3</sup> /day)								Total (m <sup>3</sup> /day)
	A	B1	B2	B3	C1	C2	D	E	
<b>qp<sub>3</sub></b>	97,711	67,940	8,273	0	0	0	2,588	0	176,512
<b>qp<sub>2-3</sub></b>	146,178	84,347	95,811	22,118	67,486	41,624	79,316	44,916	581,796
<b>qp<sub>1</sub></b>	19,834	25,243	36,245	20,715	17,899	26,553	78,148	106,712	331,350
<b>n<sub>2</sub><sup>2</sup></b>	11,715	8,239	19,966	38,022	15,100	19,825	31,293	96,062	240,221
<b>n<sub>2</sub><sup>1</sup></b>	30,433	0	17,706	16,602	8,084	0	29,266	22,263	124,355
<b>n<sub>1</sub><sup>3</sup></b>	14,393	14,374	8,528	2,116	702	0	2,600	0	42,713
<b>Total</b>	320,265	200,142	186,529	99,573	109,270	88,002	223,212	269,952	1,496,947

**Table 4:** Dynamic reserve in ecological regions.

The potential fresh groundwater exploitable reserve for the Camau peninsula area is estimated as about 11,340,100m<sup>3</sup>/day, in which: Static gravitational

reserve about 8,972,900m<sup>3</sup>/day; static elastic reserve about 870,000m<sup>3</sup>/day and dynamic reserve: 1,497,900m<sup>3</sup>/day. In each ecological region the



potential fresh groundwater exploitable reserves are presented in (Table 3) and dynamic reserves are presented in (Table 4).

Aquifers	Flow in constituents (m <sup>3</sup> /day)								Total (m <sup>3</sup> /day)
	A	B1	B2	B3	C1	C2	D	E	
qp <sub>3</sub>	39,564	37,459	6,891	0	0	0	559	0	84,473
qp <sub>2-3</sub>	82,630	62,644	65,021	20,032	19,887	9,398	39,632	23,652	322,896
qp <sub>1</sub>	8,398	16,368	29,895	17,905	10,263	12,834	35,104	56,858	187,625
n <sub>2</sub> <sup>2</sup>	6,036	844	12,103	33,092	10,384	11,207	12,764	58,774	145,204
n <sub>2</sub> <sup>1</sup>	20,130	0	8,767	14,461	4,659	0	1,812	7,573	57,401
n <sub>1</sub> <sup>3</sup>	11,177	7,422	5,332	1,752	645	0	0	0	26,328
<b>Total</b>	<b>167,935</b>	<b>124,737</b>	<b>128,009</b>	<b>87,242</b>	<b>45,838</b>	<b>33,438</b>	<b>89,871</b>	<b>146,858</b>	<b>823,927</b>

**Table 5:** Flow in fresh water to ecological regions.

**4.2 Determination of secure groundwater exploitable reserve**

The dynamic reserves displayed in (Table 4) consist of fresh water and saline water flowing to the ecological regions. It is shown that if the abstracted amount reaches these values, problem of salinity intrusion to abstracting wells is likely to happen.

Therefore it is necessary to determine the limited value to diminish the salinity intrusion process. In this paper, flow budget problems in fresh water regions were solved. As a result, fresh water flow in constituent is 823,927m<sup>3</sup>/day (rounded as 823,900m<sup>3</sup>/day). Flow in fresh water constituents to each ecological region are shown in (Table 5).

Aquifers	Secure fresh groundwater exploitable reserve (m <sup>3</sup> /day)								Total (m <sup>3</sup> /day)
	A	B1	B2	B3	C1	C2	D	E	
qp <sub>3</sub>	35,607	33,713	6,202	0	0	0	503	0	76,025
qp <sub>2-3</sub>	74,367	56,380	58,519	18,029	17,898	8,458	35,669	21,287	290,607
qp <sub>1</sub>	7,558	14,732	26,905	16,114	9,237	11,550	31,594	51,172	168,863
n <sub>2</sub> <sup>2</sup>	5,432	759	10,893	29,783	9,346	10,086	11,488	52,897	130,684
n <sub>2</sub> <sup>1</sup>	18,117	0	7,890	13,015	4,193	0	1,630	6,815	51,661
n <sub>1</sub> <sup>3</sup>	10,059	6,679	4,799	1,577	581	0	0	0	23,695
<b>Total</b>	<b>151,141</b>	<b>112,263</b>	<b>115,208</b>	<b>78,518</b>	<b>41,254</b>	<b>30,095</b>	<b>80,884</b>	<b>132,172</b>	<b>741,534</b>

**Table 6:** Secure fresh groundwater exploitable reserve in ecological regions.

From results of total natural recharge (dynamic reserve of fresh water) by flow budget in Table 5, the

secure exploitable reserve was determined as 741,500m<sup>3</sup>/day, approximately 90% of total fresh

water recharge or total flow in amount. Concrete values for every ecological region are displayed in (Table 6).

### 4.3 Result assessment

Generally, in the entire Camau peninsula groundwater abstraction is 633,522 m<sup>3</sup>/day, making about 85.4% of the secure exploitable reserve. Thus, it is possible to increase groundwater abstraction amount about 108,000 m<sup>3</sup>/day in case abstraction wells are reasonably assigned (far from salinity interface). However, in each particular ecological region, in coastal areas abstraction amount already exceeds the secure exploitable reserve in some aquifers, such as: In region C1 (qp<sub>2-3</sub> and qp<sub>1</sub> aquifers), in region D (qp<sub>3</sub> and qp<sub>2-3</sub> aquifers), in region E (qp<sub>2-3</sub> and n<sub>2</sub><sup>2</sup> aquifers). Particularly, in the region C2 the abstraction amount not only exceeds the secure exploitable reserve in aquifers qp<sub>2-3</sub>, qp<sub>1</sub> and n<sub>2</sub><sup>2</sup> but also exceeds the total secure exploitable reserve of the entire area. The excessing value over the secure exploitable reserve is not large, in range of 47÷2,491m<sup>3</sup>/day. That shows a local salinity intrusion process, and it is rather matches with the reality. In some areas such as Nam Can, Ngoc Hien, An Minh, An Bien, Dong Hai, Vinh Chau there are rather many abstracting wells

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with small discharge of total dissolved solids 1.0÷1.5 g/l (after hydrocensus data of water resources management projects in Ca Mau, Soc Trang and Hau Giang provinces). Method and implementation process stated in this paper can be applied for other area having similar natural conditions as Camau peninsula.

### 5. Conclusion

The secure exploitable reserve is a new concept aiming at groundwater exploitation management towards sustainability orientation. However, so far there has been no legitimate instruction for determining this value. In this paper, the problem is approached by digital modeling method in combination with sustainability index of UNESCO. Implementation technical method is using digital model with GMS 10.2 software and input data from reliable study wells, collected from specialized agencies. The simulation rather matches with reality, with error less than ± 0.5m. Determined value of secure exploitable reserve in Camau peninsula is about 741,500m<sup>3</sup>/day. This reserve value can be used in groundwater exploitation management, planning groundwater resources in localities of the area.

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