MINISTRY OF EDUCATION AND TRAINING
THE UNIVERSITY OF DANANG

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IMPACTS OF GROUNDWATER EXPLOITATION ON SALTWATER INTRUSION AND LAND SUBSIDENCE: A CASE STUDY IN TRA VINH PROVINCE

Speciality: **Construction of hydraulic engineering**
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DISSERTATION SUMMARY

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INTRODUCTION

1. STUDY ISSUES

Surface and groundwater resources are used for agriculture, domestic water supply and socio-economic purposes. In order to serve the needs of water, many countries in the world including Vietnam utilized groundwater sources. However, excessive groundwater extraction will cause adverse effects such as the decline of groundwater level, and thus land subsidence and saltwater intrusion inland [92].

Exploitation of groundwater has caused subsidence in the Mekong Delta with the average about 0.18m within 25 years. The rate of subsidence currently has exceed 0.025m, 2.5m/century larger than sea-level rise (climate change) of 0.5m/century, and the subsidence rate is greater than the natural sedimentary of the Mekong River [15]. The most significant subsidence is in Can Tho city, up to about 0.017m/year for the period of 1993÷2013 [75].

In the process of groundwater exploitation the light water is replaced by the sea water; and the intrusion of sea water deep into the land can affect the quality of water from pumping wells. Parallelly, the exploitation of groundwater in the coastal areas is a sensitive issue and needs a strict management if the water quality deterioration is due to the encroachment of the sea [100].

Tra Vinh is a coastal province and primarily takes groundwater for households, industry and agriculture usage. Therefore, the evaluation of land subsidence and saline intrusion into the groundwater layer is an urgent issue in Tra Vinh province.

2. RESEARCH PURPOSES

- To evaluate the current state of exploiting, use as well as the fluctuating water level groundwater.
- Determine the causes of the land subsidence and the saline intrusion into coastal aquifer when groundwater extraction.
- To evaluate land subsidence and saltwater intrusion into aquifer in the area of research.

3. THE OBJECTS AND SCOPE OF RESEARCH

- Land subsidence caused by exploitation of groundwater in Tra Vinh province.
- Saline intrusion by exploitation of groundwater in Tra Vinh province.

4. RESEARCH METHODS

- Surveys was carried out in order to understand the rudiments, data collection and analysis to evaluate hydrogeological, geological conditions in the research area.
- Data collection on the number of wells in the current exploitation area in Tra Vinh and groundwater level data changes by each year in the area of research.
- Use of formulas to determine subsidence of land with respect to time.
- Selection of mathematical models and development of algorithms and computational programs, boundary conditions, input data in order to find a solution.
- Using the logic analysis to describe the process of saline intrusion when pumping wells were exploited; and the

comparison between the numerical method and analytical solution to check the calculation results.

- Expert methods: to interview/discuss with the experts advisors, scientists, colleagues on the research field.

5. DISSERTATION STRUCTURE

The structure of the dissertation includes introduction, four chapters, conclusions and recommendations.

Introduction

Chapter 1: Overview of land subsidence and saltwater intrusion due to groundwater extraction.

Chapter 2: The mechanism of land subsidence and differential equation system of salinity intrusion.

Chapter 3: The theoretical basis of calculation of land subsidence and differential equation system solution of salinity intrusion.

Chapter 4: Evaluation of land subsidence and saltwater intrusion on aquifer coastal in Tra Vinh province due to groundwater extraction.

The conclusions and recommendations.

6. CONTRIBUTION OF THE DISSERTATION

The dissertation has new some contributions to sciences as following:

- Evaluation the level of land subsidence based on considering the value of drawdown by exploitation and the thickness of soft clay large layer geology (20m÷ 40m) in the area of Tra Vinh province.

- Applied computer programs to calculate the salinity intrusion into the aquifer by excessive groundwater extraction in the coastal area of Tra Vinh province.

- Dual impact assessment of "***saline intrusion and land subsidence***" by excessive groundwater extraction in the coastal area of Tra Vinh province.

CHAPTER 1: OVERVIEW OF LAND SUBSIDENCE AND SALTWATER INTRUSION DUE TO GROUNDWATER EXTRACTION

1.1 GENERAL

Areas near the sea, freshwater and saltwater maintain equilibrium and the saltwater is heavier; therefore it is located at the lower level. A diffused interface exists between them and the density of water is gradually decreasing from the sea to the freshwater (Figure 1.1). The region of disturbance or the transition region have different thicknesses depending on the environment the coast of the aquifer groundwater. When saline intrusion is defined as saltwater line flows into the system the aquifer [112].

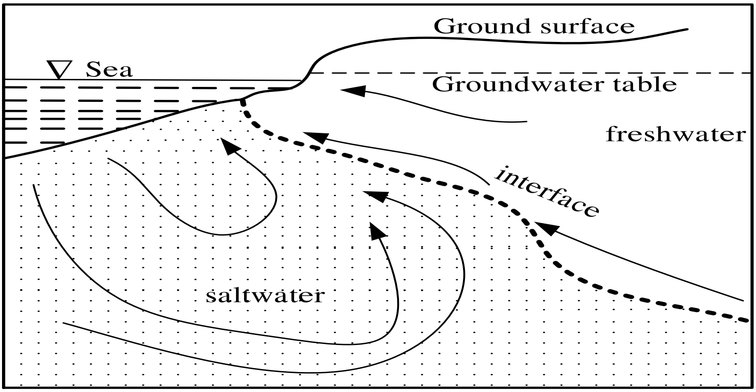

Figure 1.1: Freshwater and saltwater interface

Land subsidence is definded as a skewed situation as opposed to the surrounding terrain or to the sea level. Subsidence is the natural phenomenon caused by earthquakes, tectonic movement, erosion and sea-level rise or artificial causes including the groundwater, oil, gas, coal mining, ore, the underground excavation for the tunnels and caves. Most of the major subsidence area has occurred since the World War II due to the rapidly increasing proportion in the use of groundwater and petroleum from the ground [35].

CHAPTER 2: THE MECHANISM OF LAND SUBSIDENCE AND DIFFERENTIAL EQUATION SYSTEM OF SALINITY INTRUSION

2.1 THE MECHANISM OF LAND SUBSIDENCE DUE TO GROUNDWATER EXTRACTION

According to Galloway et al., (1999) there are many ways to prevent or mitigate subsidence due to groundwater suction. Although the effect of subsidence is not able to reverse, some preventative solutions can be used to mitigate it. When the water level is maintained at high level in a specific location, the compaction of aquifer system and land subsidence, mainly elastic, can be recovered (Figure 2.1). Only when the water is at lower level, the groundwater layer system does not stretch and compress and the soil becomes permanent. Therefore, maintaining the level of water level will help to prevent the subsidence. However due to, hydro dynamics process, the tight compression can last long after the groundwater level decline in the stable aquifer occures [62]. To maintain the water at high level, the options may be selected including stopping or reducing the groundwater exploitation strict management of location and production of groundwater and the use of artificial recharge. Moreover, areas where they can be identifed as the areas prone to subsidence can be limited to the use of groundwater (Figure 2.1) [61].

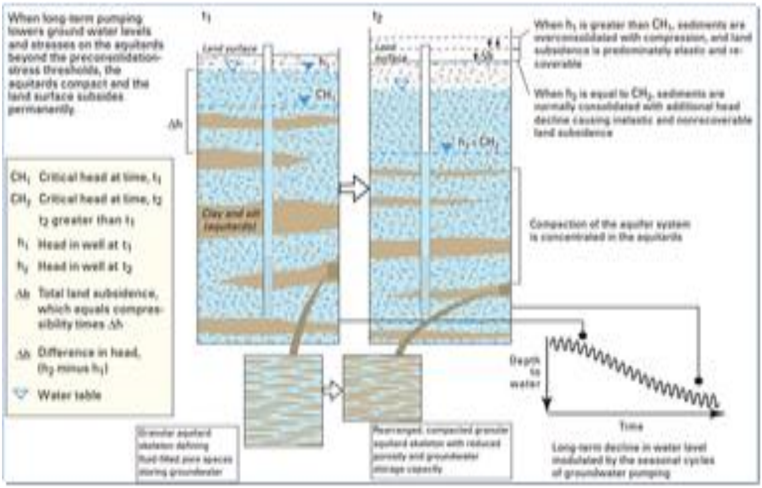

Figure 2.1 Relationship between the change in water level affecting the subsidence of the ground and non-elastic compression [61].

In parallel, Minderhoud et al., 2015 indicated that the process of the ground subsidence includes deep and shallow subsidences. Shallow subsidence is due to the load of construction works on the ground (the local subsidence) and deep subsidence is due to the extraction of liquid in the ground (subsidence) (Figure 2.2) [88].

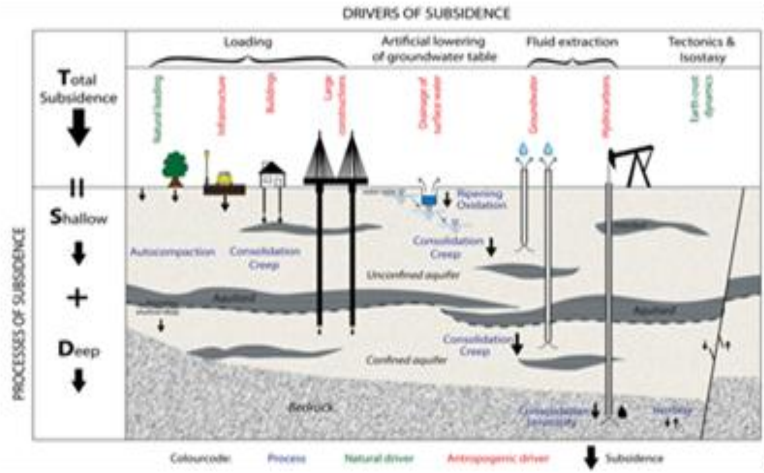

Figure 2.2: Schematization of the process of main subsidence and the subsidence within the upper (phreatic) aquifer and deeper (confined) aquifer [88].

2.2 DIFFERENTIAL EQUATION SYSTEM OF SALTWATER INTRUSION IN COASTAL REGION

The equation of motion with two horizontal-dimensions confined aquifer:

Aquitards surface below and above described by the face: $Z=-H_1$ and $H_2=-Z$. The thickness of the aquifers: $H=H_1-H_2$.

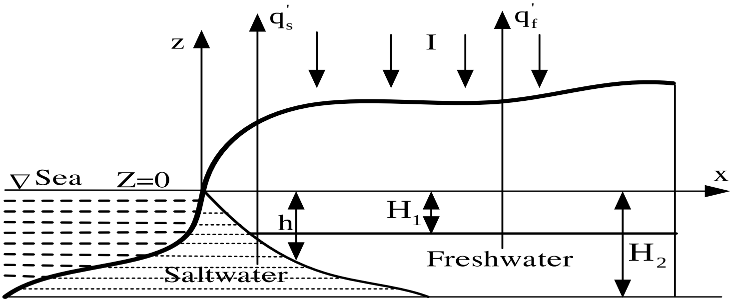

Figure 2.3: A confined aquifer

We have a system of differential equations:

$S_0\partial h/\partial t = I_f + \nabla.\{K(h-H_2)\ \nabla\phi_f\} + q'_f$ (2.1)

$-S_0\partial h/\partial t = I_s + \nabla.\{K(H_1-h)\ \nabla\phi_f\} - \nabla.\{\alpha K(H_1-h)\ \nabla h\} + q'_s$ (2.2)

Plus side by side of two equations (2.1) and (2.2) we get:

$-\nabla.\{T\nabla\ \phi_f\} = I_f + I_s - \nabla.\{\alpha K(H_1-h)\ \nabla h\} + q'_f + q'_s$ (2.3)

The above equations become:

$-\nabla.(\alpha T\ \nabla f) + \nabla.(\alpha Ta\nabla h) = I_f + I_s + q'_f + q'_s$ (2.4)

$S_0\partial h/\partial t - \nabla.(\alpha Ta\ )\nabla h + \nabla.(\alpha Ta\ \nabla f)\ = -I_s - q'_s$ (2.5)

The above differential equation system has two variables ϕ_f and h that will have the solution corresponding to the boundary conditions and initial conditions.

The two equations of unconfined and confined flows including the pair of differential equations (2.4) and (2.5) with the same symbols but with different values in the following terms:

For unconfined flow:

$f = h_f/\alpha$; $T = K(H_1+h_f)$; $Ta = T(H_1-h)/(H_1+h_f)$.

For confined flow: $f = \phi_f/\alpha$; $T=K(H_1-H_2)$; $T_a=T(H_1- h)/(H1-H_2)$.

where: T is transmissivity coefficient of aquifer, with aquifer anisotropic $T=(T_x,T_y)$; where: T_x, T_y are the coefficients of transmissivity in x, y directions.

For the convenience of the notations above, two differential equations (2.4) and (2.5) can be combined into an equation system as following [13]:

$-\nabla.(\alpha T\ \nabla_f) + \nabla.(\alpha T_a\nabla h) = I_f + I_s + q'_f + q'_s$ (2.6)

$S_0\partial h/\partial t - \nabla.(\alpha T_a\ )\nabla h + \nabla.(\alpha T_a\nabla f) = -I_s - q'_s$ (2.7)

where: $f = \dfrac{(1-\beta)\times h_f + \beta\times\phi_f}{\alpha}$; $T = K\left[H_1 + (1-\beta)h_f - \beta H_2\right]$;

$$T_a = T\frac{(H_1 - h)}{[H_1 + (1-\beta)h_f - \beta H_2]}$$

And with $\beta=1$ if the aquifer is confined; $\beta=0$ if the aquifer is unconfined.

where: ρ_f denotes density of freshwater (KN/m^3); ρ_s denotes density of saltwater (KN/m^3); S_0 denotes the storativity; t denotes the time (day); h_f denotes the freshwater head above sea level (m); ϕ_f denotes the piezometric head for freshwater (m); ϕ_s denotes the piezometric head for saltwater (m); $q_f^{'}, q_s^{'}$ denote the freshwater and saltwater sink (m^3/day); I_f, I_s denote the freshwater and saltwater recharge in aquifer (m); K_x, K_y denote the hydraulic conductivity in the x, y directions (m/day)(Figure 2.3).

CHAPTER 3: THE THEORETICAL BASIS OF CALCULATION OF LAND SUBSIDENCE AND DIFFERENTIAL EQUATION SYSTEM SOLUTION OF SALINITY INTRUSION

3.1 CALCULATION OF LAND SUBSIDENCE

3.1.1 1D consolidation of clay layers adjacent to the pumped aquifers

The theory of one-dimensional consolidation of a clay layer introduced by Terzaghi in 1925 is the basis solution for many practical soil mechanics and settlement problems, particularly to calculate the magnitude and rate of settlement or compaction that occur in fine-grained sediments under a given change in load (stress).

3.1.2 Calculation of land subsidence due to groundwater extraction

3.1.2.1 The compression of clay layers (aquitard)

Total settlement of any ground at a point $S_c = S_{cf} + S_i + S_t$

where: S_{cf} is primary consolidation settlement, S_i: immediate settlement, S_t: consolidation settlement over time [1].

The time-dependent compression of a clay layer can be calculated as follows:

$$S_{oed} = \sum_{i=1}^{n} h_i \times \left[RR \times \log\left(\frac{\sigma'_p}{\sigma'_{v0}}\right) + CR \times \log\left(\frac{\sigma'_{vf}}{\sigma'_p}\right)\right] \quad (3.1)$$

where: h_i is thickness of the calculated sub-soil layer (m), CR and RR are compression and re-compression ratio, σ'_{v0} is existing overburden (kPa), σ'_p is pre-consolidation pressure (kPa), and σ'_{vf} is the calculated final effective vertical stress (kPa).

3.1.2.2 The elastic compression of an aquifer (aquifer):

$$S_a = b \times S_s \times \Delta H \quad 3.2$$

where: S_a is settlement of the sand layer (m); b is the thickness of the sand layer (m); S_s is the coefficient of specific storage (1/m), ΔH is the drawdown of different levels (m).

The total subsidence (S) at a point on the ground surface is the sum of the compression of all aquifers (coarse-grained layers) and aquitards (fined-grained layers) above that point caculated as follows:

$$S = \sum_{i=1}^{n} S_c + S_a \quad (3.3)$$

where: n is the number of soil layer under consideration, i is the soil layer index (either sand or clay). S_c, S_a are settlements of clay and sand layer (m).

3.2 SOLVING DIFFERENTIAL EQUATION OF SALINE INTRUSION INTO COASTAL AQUIFER

3.2.1 Differential equation system:

In Chapter 2, it outlined differential equation system of the separated interface between fresh water and salt water in coastal groundwater in the coordinates Descartes as follows:

$$-\left[\frac{\partial}{\partial x}(\alpha T_x \frac{\partial f}{\partial x})+\frac{\partial}{\partial y}(\alpha T_y \frac{\partial f}{\partial y})\right]+\left[\frac{\partial}{\partial x}(\alpha T_{ax} \frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(\alpha T_{ay} \frac{\partial h}{\partial y})\right]=I_f+I_s+q_f^{'}+q_s^{'} \quad (3.4)$$

$$S_0 \frac{\partial h}{\partial t}-\left[\frac{\partial}{\partial x}(\alpha T_{ax} \frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(\alpha T_{ay} \frac{\partial h}{\partial y})\right]+\left[\frac{\partial}{\partial x}(\alpha T_{ax} \frac{\partial f}{\partial x})+\frac{\partial}{\partial y}(\alpha T_{ay} \frac{\partial f}{\partial y})\right]=-I_s-q_s^{'} \quad (3.5)$$

3.2.2 Diagram calculation

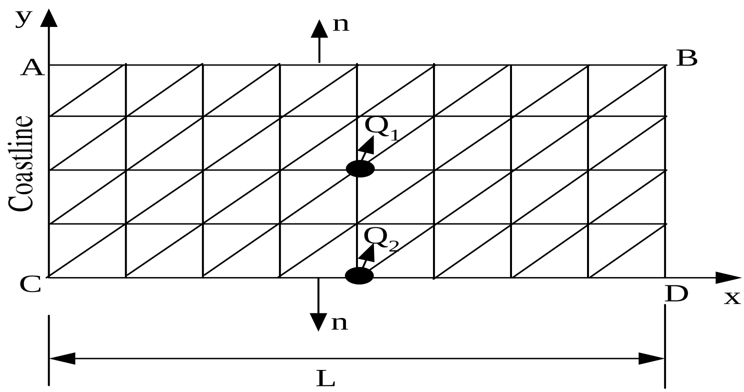

Figure 3.1 Diagram with quadrilateral elements

3.3 BLOCK DIAGRAMS AND COMPUTER PROGRAM:

Solution of equation interface mentioned in the two horizontal dimensions based on the finite element method with the programming languages Fortran according to the block diagram has been presented in [13], [38]. Detailed calculation programs with Fortran programming language, the program was named the HVH properties program.

CHAPTER 4: EVALUATION OF LAND SUBSIDENCE AND SALTWATER INTRUSION ON AQUIFER COASTAL IN TRA VINH PROVINCE DUE TO GROUNDWATER EXTRACTION.

4.1 NATURAL CHARACTERISTICS RESEARCH

4.1.1 Hydrogeological characteristics

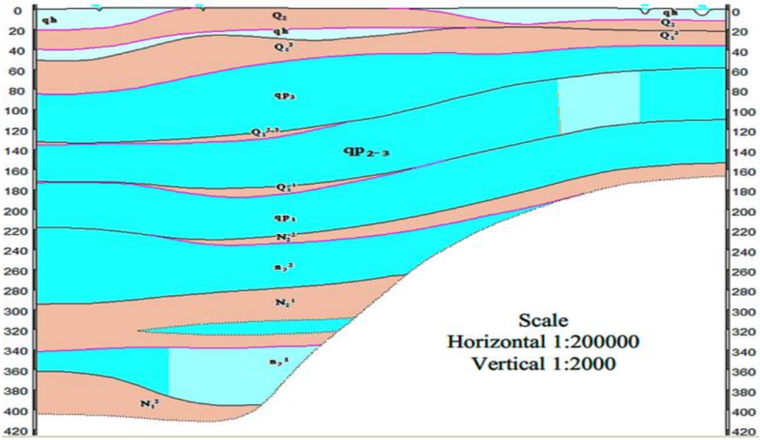

Figure 4.1: Cross-section of hydrogeology I-I [22]

4.1.2 *Geotechnical characterization*

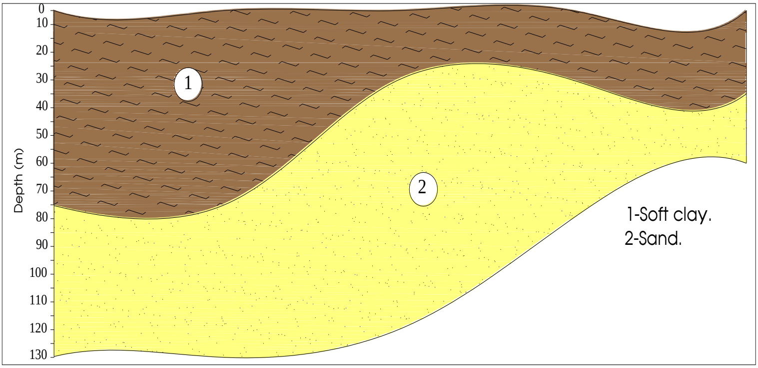

Figure 4.2: Geological cross-section in E-W direction [4]

4.2 EVALUATION OF LAND SUBSIDENCE DUE TO GROUNDWATER EXTRACTION IN TRA VINH PROVINCE

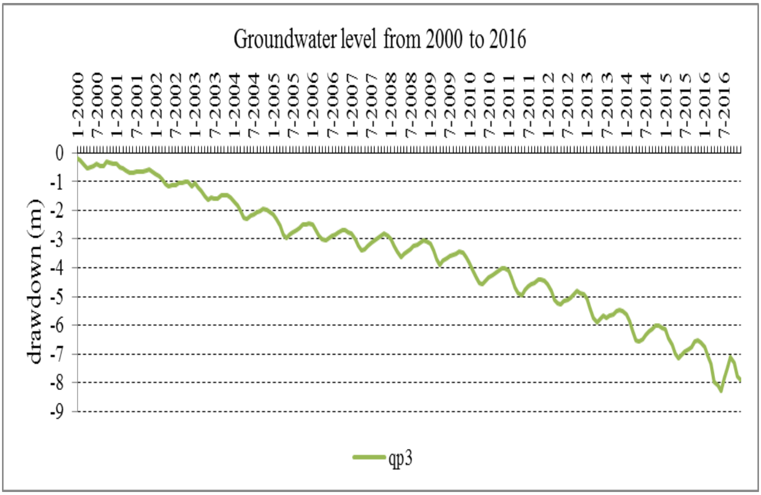

Figure 4.3 Groundwater drawdown on average in the national monitoring stations [12].

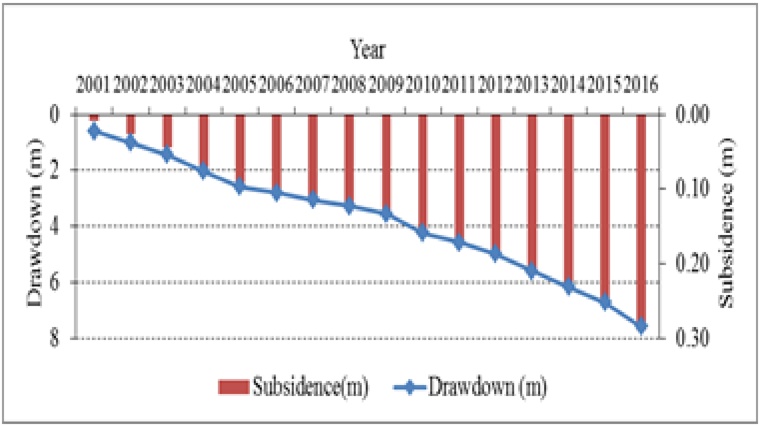

Figure 4.4 The relationship between drawdown and land subsidence

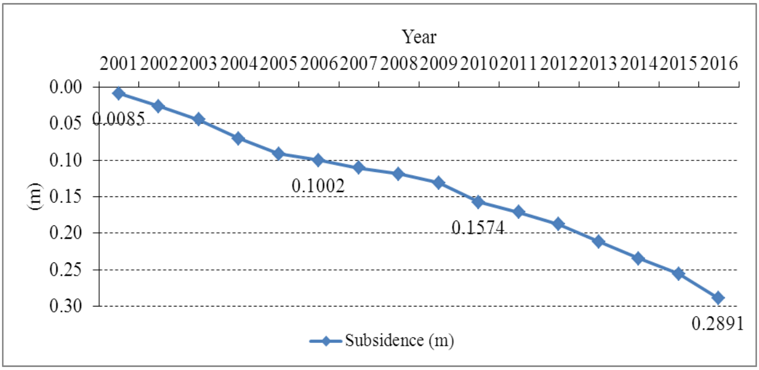

Figure 4.5 Land subsidence over time

The calculation results in Figure 4.4 and 4.5 showed that the subsidence values over time corresponding to the groundwater level was lower. The subsidence value varies depending on the depth of the lowered water ground level which caused difference in the subsidence speed by each year. In the year 2001, when the lower water level is 0.6m, the subsidence is 0.085m. After 16 years (2016), the lower level is 7.59m and the corresponding subsidence is 0.2891m, with the average subsidence of 0.1403m in 2001÷2016 the average subsidence rate is 0.0175m/year. In the period 2006÷2010, the average subsidence rate is 0.0114m/year. These values of subsidence are approximately equal to those of [56]. The subsidence calculation results is almost equal to the value of subsidence [89].

4.3 CALCULATION OF THE SALINITY INTRUSION CAUSED BY GROUNDWATER EXPLOITATION IN COASTAL AREA OF TRA VINH PROVINCE

The area of Tra Vinh province is modeled into rectangular, to calculate the saline intrusion. This area is modeled into the problem of two horizontals dimensions.

4.3.1 Two horizontals dimensions equation solution based on the finite element method

4.3.1.1 Diagram calculation:

If the domain survey via the symmetry axis ox:

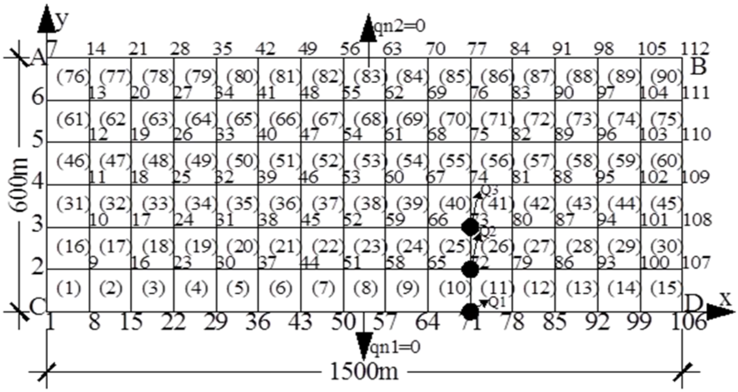

Figure 4.6: Domain calculated with quadrilateral elements spacing 100m nodes

- If the domain survey asymmetry, it needs meshing for each region (applied calculation for the coastal province of Tra Vinh).

Table 4.1. The water level and the average salinity in the Co Chien and Hau river in the late season in 2025 (see appendix 8) [8].

River	**Water level (m)**	**Salinity (g/l)**
Co Chien	0.55	7.56
Hau	0.44	7.45

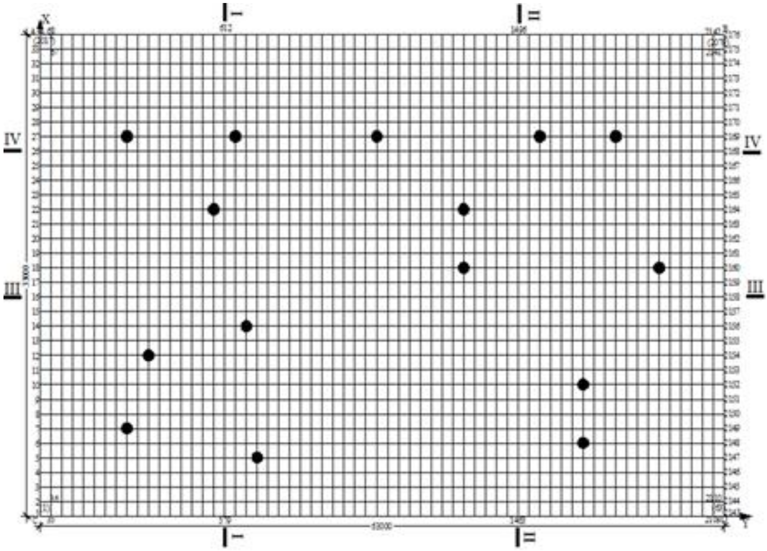

Figure 4.7: Chart of calculation and layout of pumping wells in the study area

4.3.1.2. Boundary and initial conditions

- Case of symmetry and case of asymmetry

4.3.1.3. Calculation results

- Case of symmetry:

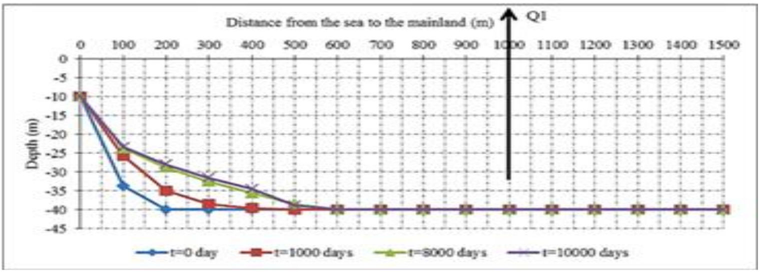

Figure 4.8: The position and depth of the interface by time at the section through the well Q1

- Case of asymmetry:

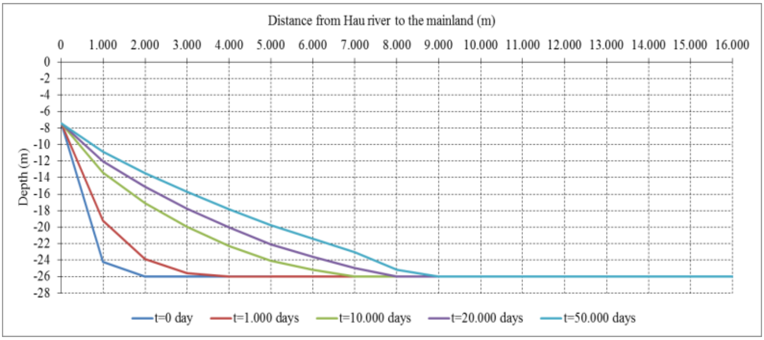

Figure 4.9: The position and depth of the interface by time at the section I-I

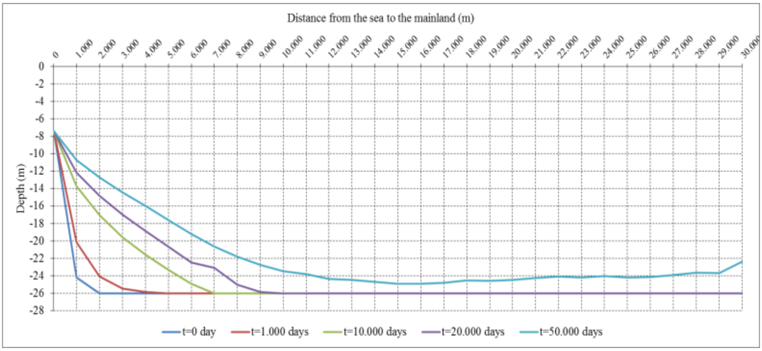

Figure 4.10: The position and depth of the interface by time at the section IV-IV

Table 4.2 The displacement value of salinity (m) compared to the position of saltwater toe over time (day)

Time (day)	Cross-section I-I		Cross-section II-II		Cross-section III-III	Cross-section IV-IV
	From	From	From	From	From	From

	Hau river	Co Chien river	Hau river	Co Chien river	sea	sea
t=0	1,236	1,236	1,236	1,236	1,236	1,236
t=10,000	6,800	6,900	7,000	7,000	7,000	7,000
t=50,000	8,500	9,000	9,000	8,800	12,500	0,0

4.3.2 Checking the program

4.3.2.1. Theis formula [3]

$$T = \pm\frac{n}{v}\left[x_1 - x_A \times \ln\left(\frac{x_1}{x_A} + 1\right)\right]$$

Substitute the actual values as n=0.3%, K=8.5m/day, b=30m, the total flow of the extraction 3 wells $Q=Q_1+Q_2+Q_3=$ $120+120+120=360m^3$/day, the calculation area is perpendicular to the coast the axis ox = 1,500 m, along the coast of the axis oy = 600m, $q = \frac{360}{600} = 0.6m^2 / \text{day}$

where:

$$x_0 = \frac{0.025 \times 8.5 \times 30^2}{2 \times 0.6} = 159.4\text{m} \quad x_1 = \sqrt{\frac{360 \times 10{,}000}{3.14 \times 0.3 \times 30}} = 356.9\text{m}$$

At the beginning, the salinity boundary is at x_0=159.4m, after the extraction time of 10,000days $\approx$ 27.39years, the salinity boundary will reach to the mainland about 356.9m, 516.3m from the shore, 483.7m from the well.

4.3.2.2 Superposition formula

Superposition formula was used to calculate the potential energy of the flow of a coastal region with many different extraction pump wells [42]:

$$\phi = \frac{q}{K}x + \sum_{i=1}^{n}\frac{Q_i}{4 \times \pi \times K}\ln\left[\frac{(x - x_i)^2 + (y - y_i)^2}{(x + x_i)^2 + (y - y_i)^2}\right]$$

Substitute the actual values such as: $q=0.6m^2/day$, $K=8.5m/day$, $b=30m$, $Q_1=120m^3/day$, $Q_2=120m^3/day$, $Q_3=120m^3/day$ into equation, we have:

$$\phi = \frac{0.6}{8.5}x + \frac{120}{4\times 3.14\times 8.5}\times \ln\left[\frac{(x-1000)^2+(y-100)^2}{(x+1000)^2+(y-100)^2}\right]$$

$$+\frac{120}{4\times 3.14\times 8.5}\times \ln\left[\frac{(x-1000)^2+(y-0)^2}{(x+1000)^2+(y-0)^2}\right]$$

$$+\frac{120}{4\times 3.14\times 8.5}\times \ln\left[\frac{(x-1000)^2+(y+100)^2}{(x+1000)^2+(y+100)^2}\right]$$

With the potential energy of the saline wedge to be determined according to the formula:

$$\phi = \frac{0,025}{2}\times 30^2 = 11.25m^2.$$

So, with each value of $\phi=11.25m^2$; $\phi=9.02m^2$; $\phi=7.02m^2$; $\phi=5.02m^2$ we have value of each pair of coordinates (x, y) then the diagram is drawn as follows:

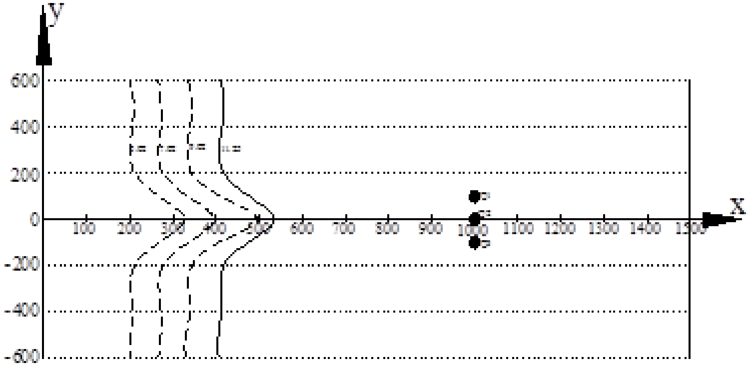

Figure 4.11: The moving into saline wedge

So, with value ϕ =11.25m^2 the solid line in Figure 4.11 showed the position of the saline wedge when simultaneous exploitation of the three wells and saltwater wells is 534.4m far from the coastline, 465.4m away from the pavement, respectively.

4.3.2.3 Checking and discussing the calculation results

Table 4.3: The position of saltwater toe according to methods

X	Theis formula	FEM method	Superposition formula
The distance from the coast to the farthest saltwater toe position (m)	516.3	525.0	534.4

4.3.3 Calculating the salinity intrusion into the upper-middle pleistocene aquifer in Tra Vinh province

4.3.3.1. The diagrams of layout, flow and coordinates of the extraction wells

4.3.3.2. Calculation diagram

4.3.3.3. Boundary and initial conditions

4.3.3.4. Results and discussion

The program was calculated by Fortran, with HVH program was developed based on [13], [38]. This program is written in the form of aggregate calculations, have put more weight added calculation modules (rainfall), softened and more full input and output of materials for the computer program to suit the actual conditions in the coastal province of Tra Vinh.

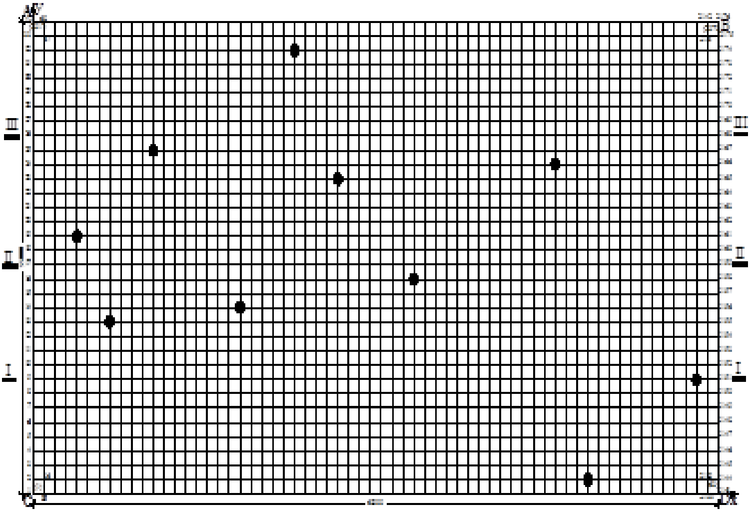

Figure 4.12: Chart of calculation and layout of pumping wells in the study area

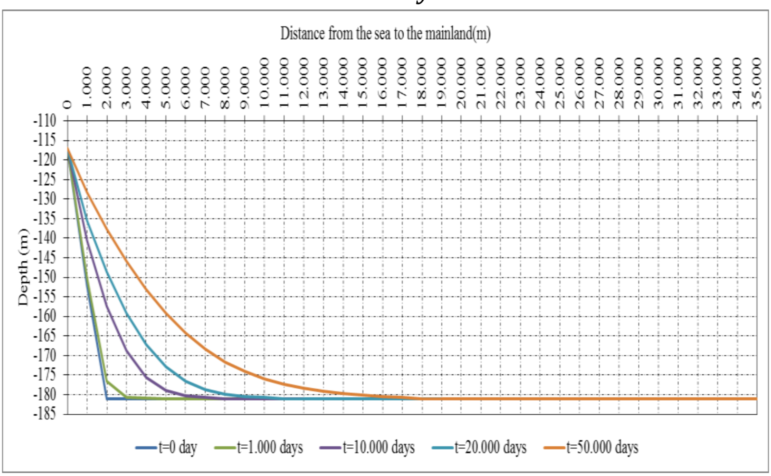

Figure 4.13: The position and depth of the interface along Hau river by time

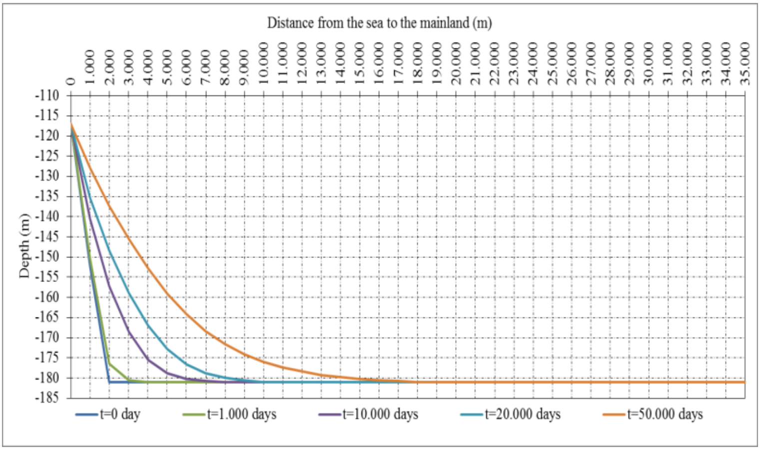

Figure 4.14: The position and depth of the interface along cross-section II-II by time

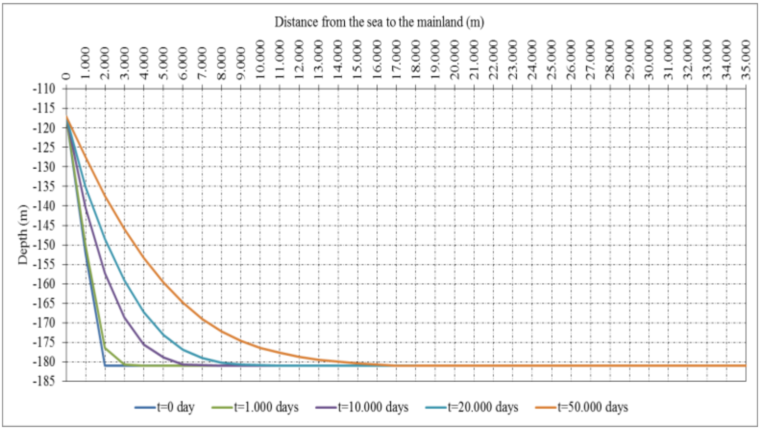

Figure 4.15: The position and depth of the interface along Co Chien river by time

Table 4.4 The displacement value of salinity compared to the position of saltwater toe over time

Cross-section	*Distance from the coast to the farthest saltwater toe position (m)*		
	t=0day	*t=10,000days*	*t=50,000days*
Along Hau river	2,019	14,000	18,000
I-I	2,019	8,000	15,000
II-II	2,019	10,000	18,000
III-III	2,019	7,000	18,000
Along Co Chien river	2,019	12,000	18,000

CONCLUSIONS

Land subsidence: This research reviews the situation of land subsidence in Tra Vinh, with data including geological data, pumping discharge and the value of ground water low level over time was collected The calculation results in this research shows that, in the area of Tra Vinh province the average subsidence rate is 0.0114m/year for the period 2006÷2010; the rate of this land subsidence is nearly equal to the calculated value of [56] (average rate of 0.016m/year). This indicates that land in Tra Vinh is vulnerable to subsidence caused by groundwater exploitation (drawdown) especially with the soft clay layer thickness (20m÷40m). The method of calculation of subsidence in this research provides a useful tool to estimate land subsidence in Tra Vinh while ground subsidence observation data are not yet available. Moreover, the database in this study is useful for other purposes such as planning and implementation of infrastructure construction in Tra Vinh province in the near future.

Saltwater intrusion: The mathematical model of salinity intrusion into the aquifer for the coastal area has been applied to confined aquifer coastal in Tra Vinh province. The calculation results are identified as follows:

- The separated interface corresponding to the arrangement of the well which have the coordinates allocated in horizontal flat surface in xy any at a time certain determined the location and shape.

- Determining the depth and shape of boundaries that salinity moves into the mainland from the sea over time, depending on the location of the different cross-section in the calculation area.

- Evaluating the level of salinity intrusion into the upper-middle Pleistocene (qp_{2-3}) and Holocene (qh) aquifer over time corresponding to the specific exploitation flows. Based on this, the model can predict the salinity intrusion into the aquifer over time corresponding to the different exploitation flows.

- Algorithms and calculation programs can be calculated for all confined and unconfined aquifers, corresponding to different areas in the coastal zone.

- The results of this calculation are significant for planning, laying out wells and forecasting salinity intrusion so that the managers can devise feasible plans for exploiting groundwater in order to meet the need of the socio-economic development needs, and also to ensure the sustainable development of Tra Vinh province as well as other coastal areas in the country and in the world.

LIST OF PUBLICATION

[1] **Huynh Van Hiep**, Nguyen The Hung (2016), "Evaluating the salinity intrusion on the main river systems in Travinh province in the dry season under the impacts of sea level rise and upstream flow decline," *Science and technology Journal of Agriculture rural development*, ISSN 1859-4581, pp 84÷90.

[2] **Huynh Van Hiep**, Nguyen The Hung, Pham Van Long (2017), "Evaluating the saltwater intrusion to aquifer upper-middle pleistocene (qp_{2-3}) in coastal area of Travinh province due to groundwater exploitation," *Proceedings of International Conference on Advances in Computational Mechanics, Lecture Notes in Mechanical Engineering, pp. 675÷690,* Publisher name: Springer, Singapore, Print ISBN: 978-981-10-7148-5, accessed February 21, 2018, at https://link.springer.com/chapter/10.1007/978-981-10-7149-2_46.

[3] **Huynh Van Hiep**, Nguyen The Hung, Pham Van Long (2017), "Evaluating the saltwater intrusion to aquifer upper-middle pleistocene (qp_{2-3}) in coastal area of Travinh province due to groundwater exploitation," *Science and technology Journal of Agriculture rural development*, ISSN 1859-4581, pp 58÷64.

[4] **Huynh Van Hiep**, Nguyen The Hung, Pham Van Long (2017), "Evaluation of land subsidence due to excess groundwater exploitation in Travinh province," *The Conference works collection of Vietnam association for fluid mechanics 20th national,* Publishing House National University of Ho Chi Minh City, ISBN 978-604-73-6070-3, *pp. 315÷327.*

[5] Nguyen The Hung, **Huynh Van Hiep**, Pham Van Long (2017), "Effects of groundwater explioted to saltwater intrusion in the coastal Travinh province area," *The Conference works collection of Vietnam association for fluid mechanics 20th national,* Publishing House National University of Ho Chi Minh City, ISBN 978-604-73-6070-3, *pp. 380÷390*.

[6] Tran Van Ty, **Huynh Van Hiep** (2017), "Groundwater exploitation status and groundwater level declines and land subsidence relationship: A case study in Travinh and Cantho", *Cantho University Journal of Science* No.1, ISSN: 1859-2333, pp. 128-136.

[7] Tran Van Ty, Le Van Phat, and **Huynh Van Hiep** (2018), "Groundwater Level Prediction Using Artificial Neural Networks: A Case Study in Tranoc Industrial Zone, Cantho City, Vietnam", *Journal of Water Resource and Protection*, 10, pp.870-883. https://doi.org/10.4236/jwarp.2018.109050.