An Alternative Groundwater Exploitation Policy for Land Subsidence Prevention – A Case Study for Pingtung Plain Coastal Area, Taiwan

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ABSTRACT

Land subsidence basically is the deprivation of water and earth resources, further inducing social and economical undesirable impact. The principal direction of land subsidence prevention is properly management of groundwater. However groundwater management should be developed on the basis of combined technical, economical, social and institutional approaches to management that reflect local conditions and can be adapted and evolved. Therefore, the aim of this paper is to make land subsidence prevention strategies for government to refer.

Before year 1969, agriculture was the main land utilization business in Pingtung Plain. Due to intensive development of fish breeding after 1970's, the aquaculture area along the coastal region of Pingtung Plain have been dramatically increased. Groundwater thus became the main fresh water resource for aquacultural water diluting and flushing because of the insufficiency in surface water supply. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the south where aquaculture is concentrated. These effects are land subsidence (at some places more than 3mm), saline water intrusion, lowering of water tables and reductions in well yields.

Government stressed on the improvement of breeding technology in the past, which mainly focused on the water quality control in order to raise the culture density, however, it neglected the impact to the environment and quantity control. This paper promotes a reasonable aquacultural water consumption policy aims at finding out the most suitable breeding species considering water consumption and its reasonable breeding area under the premise that it will not depress the original profit of aquatic products trading.

Keyword: Groundwater, Land subsidence, Policy, Pingtung Plain

1.PREFACE

Land subsidence basically is the deprivation of water and earth resources, further inducing social and economical ill impact. The principal direction of land subsidence prevention is management, utilization and conservation of groundwater. Groundwater management should be developed on the basis of combined technical, economical, social and institutional approaches to management that reflect local conditions and can adapt and evolve (Molden, 2001). When groundwater is not over pumped yet, saturated zone is full of water. The effective stress of stratum particles in the aquifer and the water between granular structures can defend the outer pressure from the surface. Therefore, aquifer would not collapse under pressure even if there were many openings. However, over-pumping of groundwater, oil, gas etc from underground aquifer would cause groundwater table to drop. The reduction of water pressure causes loss of support for the clay and silt beds. Indirectly, upper aquifer particles are compressed and regional subsidence occurs. Land subsidence is a rather general and serious problem in many Asia major cities like Shanghai, Jakarta, Bangkok, Tokyo and Osaka.

Owing to lack of management in the past, people pumped groundwater without limit. In Taiwan, especially cities along coastal region, in order to get the cheaper and constant temperature freshwater supply, aquacultural proprietors pumped groundwater with a large scale, and that is the main cause of locally land subsidence. Due to coastal region land surfaces were lower than sea level, every time when a typhoon passed over, powerful stormy waves always made these areas flooded. Government has to keep raising the height of dikes and using pump to maintain the land utilization with difficulty. Land subsidence has already repeatedly increased the expenditure of local government for drainage works. Although relative organizations proposed many approaches on restraining groundwater utilization, but comprehensively restricted groundwater exploitation should not the only way of solving problem. Therefore, this paper aims at making an alternative groundwater exploitation strategy for land subsidence prevention.

2. BACKGROUND INFORMATION AND LITERATURE REVIEW

Before year 1969, agriculture was the main land utilization business in Pingtung Plain. Due to intensive development of fish breeding after 1970's, the aquaculture area along the coastal region of Pingtung Plain have been dramatically increased. Groundwater thus became the main fresh water resource for aquacultural water diluting and flushing because of the insufficiency in surface water supply. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the south where aquaculture is concentrated. These effects are land subsidence (at some places more than 3m), saline water intrusion, lowering of water tables and reductions in well yields (Ting, 1997).

People stressed on the improvement of breeding technology in the past, which mainly focused on the water quality control in order to raise the breeding density, however, it neglected the impact of environmental saturation and abundantly abstract groundwater. These areas used to be famous for processing and exporting aquatic products; local people became rich in several years by groundwater utilization. However, people must use fortune to remedy the cost of land subsidence inversely nowadays. Therefore, a reasonable aquacultural water consumption structure is needed.

A reasonable aquacultural water consumption structure aims at finding out the most suitable breeding species considering water consumption and its reasonable breeding area under the premise that it will not depress the original profit of aquatic products trading. It is a multi-objective function problem. In another saying is, how to effectively decrease aquaculture water consumption without affecting regional profit development would be truly an imperative problem need to deliberate. The modulation of water consumption structure between each breeding species is a possible solution.

Yang et al (2001) proposed the fuzzy multi-objective function to resolve relative problems in Beishrliau district, and applied global optimization algorithm to find out suitable aquaculture scenarios in the demonstration district. As we know multi-objective function represents no single optimum solution existing, but in contrast, there could be many possible solutions (non-inferior solutions). Because of that, considerations can therefore be made in some ideal solutions, which can achieve the requirements as closer as possible.

The result presented the most perfect scenario of breeding species, water demand and decrement, and the ideal profit. Although theoretically it offered the fisheries authorities as a perfect arrangement of aquaculture structure, but it is practically difficult to enforce. Land subsidence is slow and usually irreversible. It is not like land slides or typhoons, which cause obvious and direct catastrophe in a very short time. So as land subsidence prevention work, it has to advance the work gradually and continually, and then it can truly terminate groundwater over utilization and earn the identification of local people.

Therefore, a proposal on another reference direction of aquacultural water modulation in order to identify the ideal and unsuitable breeding species would be discussed below.

3. PROBLEM ANALYSIS

Aquaculture can be simply classified into marine culture and inland water culture. According to a survey of the Committee of Agriculture, Fisheries Administration (COAFA) in 2000, the area of inland water culture estimated 5104.54 ha; it was 91.7% of total aquacultural area in Pingtung County. Inland water culture can be further classified into brackish water and fresh water. During year 2000, 41.9% of inland water culture was brackish and the other 58.1% was fresh. According to the statistics of fisheries yearbook, the staple species (total breeding area larger than 100 ha) of inland aquaculture in Pingtung are Tilapia, Eel, Milkfish, Porgy, White-spotted reef-cod, Grass shrimp, Giant freshwater prawn, White shrimp and Soft-shell turtle. Relative variables of each species like breeding area, water consumption from groundwater pumping per unit area, annual production per unit area and the average price of each species are arranged as Table 1 below. Data of individual species unit area groundwater consumption comes from "Field Studies and Analysis on the Reasonable Water Use of Aquaculture (II)" issued by Liang et al in 1997, and the rest of data is issued by COAFA Fishery Yearbook in 2000. Here by author merged Grass shrimp and White shrimp together as on item called "Sea water shrimp".

Table 1 Area, groundwater consumption, production and price of each species

Species	Area (ha)	Groundwater consumption (m^3/ ha/ yr)	Production (kg/ ha/ yr)	Price ($NT/ kg)
i	***A***	***W***	***Y***	***P***
Tilapia	115	22740	7887	35
Eel	145	108580	9828	190
Milkfish	254	149380	7161	60
Porgy	336	36880	378	155
White-spotted reef-cod	567	65400	6093	220
Sea water shrimp	382	128710	4236	380
Giant freshwater prawn	2250	88350	3303	225
Soft-shell turtle	101	9000	16792	165
SUM	**4150**		1NT ≒ $34 US	

The annual total water consumption of all species ($\Sigma A_i W_i$) is 354,638,000 m^3/year, and annual total profit of all species ($\Sigma A_i Y_i P_i$) is 3,758,247,000 NT$/year. Here only two objectives are concerned; one is the decrease of total water consumption and the other is the increase of total profit. In order to apply fuzzy theory, it is necessary to define two membership functions to identify the requirement of each objective.

A membership function maps every element of the universe of discourse X to the interval [0, 1], (Tsoukalas and Uhrig, 1996), according to the fundamental equation of Yang et al (2001), two membership functions are made

$$\mu_{con} = \frac{\Sigma A_i W_i - \Sigma A_i^* W_i}{\Sigma A_i W_i - (\Sigma A_i) W_{i\,\min}}$$

$$\mu_{pro} = \frac{\Sigma A_i^* Y_i P_i - \Sigma A_i Y_i P_i}{(\Sigma A_i)(Y_i P_i)_{\max} - \Sigma A_i Y_i P_i}.$$

μ_{con} =Membership Function of total water consumption;
μ_{pro} =Membership Function of total profit;
A_i = original area of species i (ha);
A_i* = optimum area of species i (ha);
W_i = water consumption of each species i (m^3/ha/yr);
$W_{i\,min}$ = minimum water consumption of species i (m^3/ha/yr);
Y_i = annual production of each species i (kg/ha/yr);
P_i = price of each species i ($NT/kg)

4. PROPOSING STRATEGY

When the preference of each species to both consumer and government is the same, total water consumption and total profit are influenced only by the modulation of area. It is easy to discover from Table 1 that Soft-shell turtle is the most ideal species among all, because its low water consumption and high profit. Borland Delphi is applied to present the possible solution distribution. In the compiling chart of the outcome, x-axis represents the expectation of total water consumption decreasing potential, the ideal scenario should get as closer to the right as possible, because that means the scenario will consume much less water than original situation; y-axis represents the expectation of total profit increasing potential. The ideal scenario should get as closer to the top as possible, because that means the scenario will increase much higher profit than original situation. See Figure 1 below.

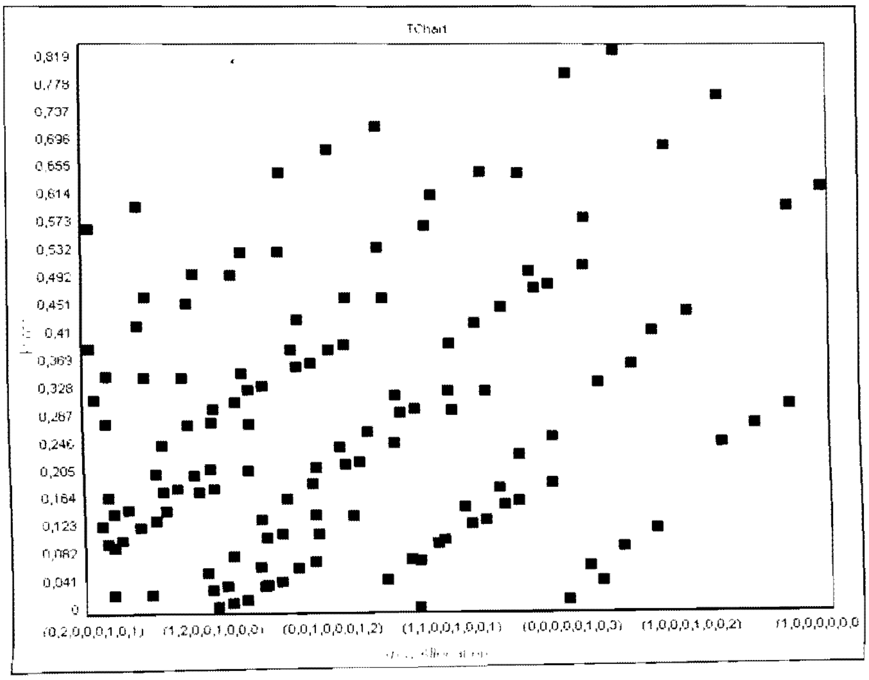

Figure 1 Ideal breeding area allocation among species (Including Soft-shell turtle)

The distribution of possible solutions is obviously influenced by the extreme value: **Soft-shell turtle**. According to the experience of soft-shell turtle breeder, because soft-shell turtle has high environmental adaptation so it doesn't need very good water quality and usually breeder doesn't need to change water in whole year. On the other hand, although soft-shell turtle has very high production, however, its main purpose is the exportation outside of Taiwan. Therefore, if Soft-shell turtle is neglected and the rest of species are taken into consideration, annual total water consumption becomes 353,729,920 m^3/year, annual total profit becomes 3,478,408,785 NT$/year and then the possible area allocation will be as presented in Figure 2 below.

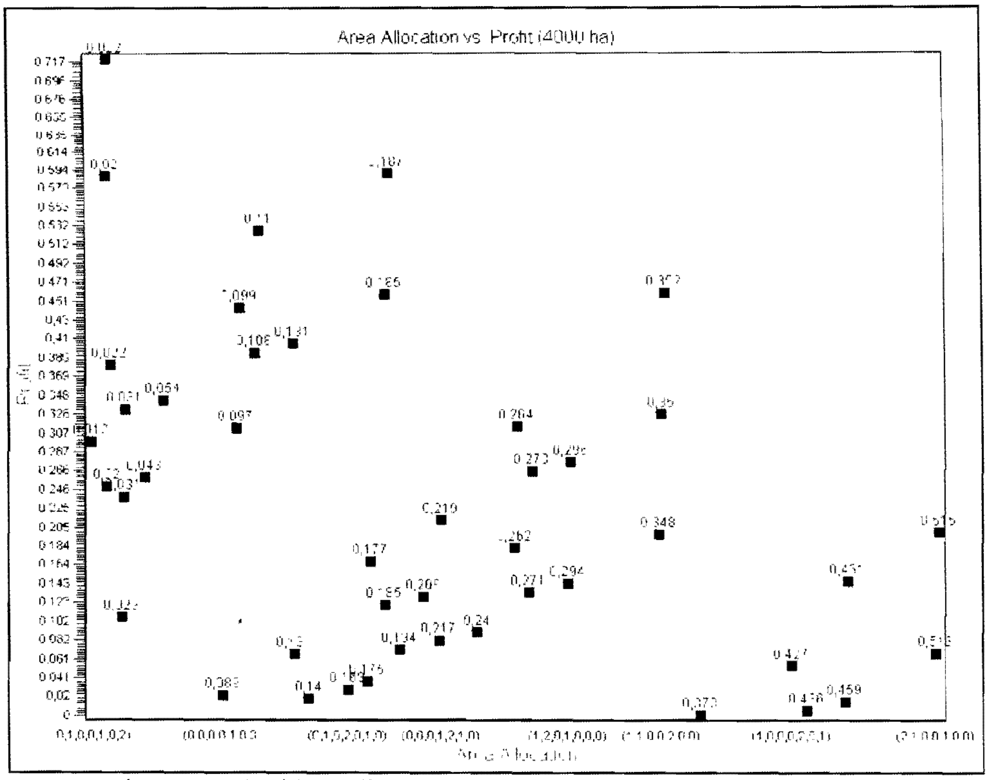

Figure 2 Ideal breeding area allocation among species (Not including Soft-shell turtle)

The label on x-axis is the distribution area of seven species in the order of Tilapia, Eel, Milkfish, Porgy, White-spotted reef-cod, Seawater shrimp, and Giant freshwater prawn. The label on y-axis represents μ_{pro} and the label above each solution point represents μ_{con}. The outcome chart above presents 45 possible area distribution ways. And the description of each solution is arranged as shown in the Table 2 below.

Table 2 Possible breeding area allocation data (Total area 4000 ha)

μ_{con}	μ_{pro}	Tilapia (ha)	Eel (ha)	Milkfish (ha)	Porgy (ha)	White-spotted reef-cod (ha)	Sea water shrimp (ha)	Giant freshwater prawn (ha)
0.515	**0.201**	**1000**	**0**	**0**	**0**	**3000**	**0**	**0**
0.513	0.069	2000	1000	0	0	1000	0	0
0.461	0.147	0	0	0	1000	3000	0	0
0.459	0.016	1000	1000	0	1000	1000	0	0
0.436	0.006	2000	0	0	0	1000	1000	0
0.427	**0.054**	**1000**	**0**	**0**	**0**	**2000**	**0**	**1000**
0.373	0.001	0	0	0	1000	2000	0	1000
0.352	**0.461**	**0**	**0**	**0**	**0**	**4000**	**0**	**0**
0.350	0.330	1000	1000	0	0	2000	0	0
0.348	0.198	2000	2000	0	0	0	0	0
0.296	0.276	0	1000	0	1000	2000	0	0
0.294	0.145	1000	2000	0	1000	0	0	0
0.273	0.267	10000	0	0	0	2000	1000	0
0.271	0.135	2000	1000	0	0	0	1000	0
0.264	0.315	0	0	0	0	3000	0	1000
0.262	0.183	1000	1000	0	0	1000	0	1000
0.240	0.091	0	2000	0	2000	0	0	0
0.219	0.213	0	0	0	1000	2000	1000	0
0.217	0.082	1000	1000	0	1000	0	1000	0
0.208	0.130	0	1000	0	1000	1000	0	1000
0.194	0.072	2000	0	0	0	0	2000	0
0.187	**0.590**	**0**	**1000**	**0**	**0**	**3000**	**0**	**0**
0.185	0.459	1000	2000	0	0	1000	0	0
0.185	0.120	1000	0	0	0	1000	1000	1000
0.177	**0.169**	**0**	**0**	**0**	**0**	**2000**	**0**	**2000**
0.175	0.037	1000	1000	0	0	0	0	2000
0.163	0.028	0	1000	0	2000	0	1000	0
0.140	0.019	10000	0	0	1000	0	2000	0
0.131	0.405	0	2000	0	1000	1000	0	0
0.131	0.067	0	0	0	1000	1000	1000	1000
0.110	0.527	0	0	0	0	3000	1000	0
0.108	**0.396**	**1000**	**1000**	**0**	**0**	**1000**	**1000**	**0**
0.099	0.444	0	1000	0	0	2000	0	1000
0.097	0.312	1000	2000	0	0	0	0	1000
0.089	0.022	0	0	0	0	1000	0	3000
0.054	0.342	0	1000	0	1000	1000	1000	0
0.043	0.259	0	2000	0	1000	0	0	1000
0.031	0.333	1000	0	0	0	1000	2000	0
0.031	0.238	0	0	1000	0	3000	0	0
0.029	0.107	1000	1000	1000	0	1000	0	0
0.022	0.719	0	2000	0	0	2000	0	0
0.022	**0.381**	**0**	**0**	**0**	**0**	**2000**	**1000**	**1000**
0.020	0.588	1000	3000	0	0	0	0	0
0.020	0.249	1000	1000	0	0	0	1000	1000
0.012	0.298	0	1000	0	0	1000	0	2000

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

According to table 2, if total aquacultural area maintains as 4000 ha then the most ideal species is **White-spotted reef-cod** and the most unsuitable breeding species is **Milkfish**; due to its high water consumption and relatively low profit.

Under the hypothesis of homogeneous preference between each species, if policy maker takes total groundwater consumption decreasing as prior consideration, and then the best area allocation would be 1000 ha of **Tilapia**, 3000 ha of **White-spotted reef-cod** and the rest with nothing. Total annual groundwater consumption of this scenario is 218,940,000m^3/year; it saves 135 Mm^3 water (*ca. 38.1% of original water consumption*) per year. And the annual total profit increases to 4,297 M $NT /year. The location of this solution is at the most right hand side in figure 2. Table 3 below represents the suggested area allocation scenario based on total area maintaining the same.

Table 3 Suggested ideal species-breeding scenario

Scenario		Annual water consumption (Mm^3/year)	How much water been saved? (%)	Annual total profit (Million NT$/year)
Present situation		**354**	**0**	**3478**
Tilapia White-spotted reef-cod	1000ha 3000ha	219	38.1%	4297
Eel White-spotted reef-cod	2000ha 2000ha	348	1.7%	6416
Eel White-spotted reef-cod	1000ha 3000ha	305	13.8%	5889
White-spotted reef-cod	4000ha	262	26.0%	5362
Giant freshwater prawn White-spotted reef-cod	2000ha 2000ha	308	13.0%	4167
Giant freshwater prawn Tilapia White-spotted reef-cod	1000ha 1000ha 2000ha	242	31.6%	3700
Tilapia Eel White-spotted reef-cod Sea water shrimp	1000ha 1000ha 1000ha 1000ha	325	8.2%	5094

But if policy maker views total profit of aquaculture more important than the other, then the best area allocation would be 2000 ha of **Eel**, 2000 ha of **White-spotted reef-cod** and the rest with nothing. Annual total profit of this area will increase to 6,416 million $NT/ year. Total annual groundwater consumption of this scenario is 347,960,000 m^3/year; it saves about 1.7% of original water consumption per year only. The location of this solution is at the most top one. In case the policy maker isn't biased against which objective then the possible solution would be either the combination between 1000 ha of **Eel** and 3000 ha of **White-spotted reef-cod** or 4000 ha of overall aquaculture area all for **White-spotted reef-cod**. The two scenarios can be saved 13.8% and 26% of original total water consumption respectively.

However, if the independent character of each variable, public opinion, government's policy and market demand structure is considered, the modification result will be different. Therefore, aquaculture area and production are individually taken into consultation.

(i) From the viewpoint of breeding area, **Giant freshwater prawn** occupies more than half of total area, in case the government decides to narrow the breeding area of Giant freshwater prawn, it will absolutely make enforcement difficult. Therefore, if the policy maker intends to keep 2000 ha of **Giant freshwater prawn** without modification, then the best allocation will be another 2000 ha for **White-spotted reef-cod** breeding. This scenario saves 13% (46 Mm^3/year) of original groundwater per year. Or to keep half of **Giant freshwater prawn** breeding area and 1000 ha region for **Tilapia** and 2000 ha region for **White-spotted reef-cod**, then it can save 31.6% (112 Mm^3/year) of groundwater consumption in a year.

(ii) From the viewpoint of production, **Eel**, **White-spotted reef-cod** and **Seawater shrimp** have relatively considerable profit. If government takes annual profit of species as the reference of modification, policy maker has to retain these three species for further breeding. So the most ideal scenario will be 1000 ha of breeding region for **Eel**, **White-spotted reef-cod, Sea water shrimp** and **Tilapia** individually. Such modification can make annual total profit reach 5,094 million $NT/year, and total water consumption also decreases to 325 Mm^3/year.

5.2 Recommendation

The process of policy-making has to consider of present situation, future development, stakeholder acceptability, government capacity etc. Especially aquaculture is a water utilization service with high subtractability, so it needs to be allocated wisely. This modulation strategy proposes government a multi-options policy making consideration, but it doesn't consider of the effect of breeding density, water quality control, and the characteristic of individual species. So it is recommended to involve them for the further research.

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