

The Characteristic of Aquifer Drawdown and Settlement of Bangkok and Vicinity Area

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ABSTRACT

Land subsidence problems in Bangkok and its vicinity have been occurring mostly by extensive of groundwater withdrawal. The pumping rate was increased from less than 1 million m³/day in 1954-1974 to more than 2 million m³/day in 1997-2003. And the result is the occurring of land subsidence with the maximum rate more than 10 cm/year. Although at the present, the subsidence rate has been decreased on the central Bangkok but on the outskirts area the subsidence still occurs about 3 cm/year. Thus, it needs to inspect the subsidence in order to protect the problems. This paper will show a relation which can be used for administration and management of groundwater pumping in each aquifer. The relation is called the Characteristic of Aquifer Drawdown and Settlement or CADS. It is a relation of the lowering of groundwater level and settlement of soil in each aquifer. The relation can be divided in 4 stages; Increase Settlement, Delay Settlement, Zero Settlement and Settlement Recovery. Each stage expresses behaviour of settlement in the soil when the groundwater level is changed in each aquifer. The CADS can be used to inspect which areas are critical settlement and which areas are sensitive to settlement when the groundwater is drawdown 1 meter. The result showed that most of the center of study area has been in the Zero Settlement and Recovery stage. This means the subsidence problem of the area has been improved which it was the result of the implemented measures of groundwater management. The east and the west of study area which were in the Increase Settlement and Delay Settlement stage have to be watched out. And the maximum value of the sensitivity of settlement is about 0.5 cm/year in two areas at Amphoe Bang Phli, Samut Prakan Province and Amphoe Mueang, Samut Sakhon Province in PD and NL aquifers respectively

KEYWORDS: Characteristic aquifer, groundwater drawdown, land subsidence.

INTRODUCTION

Land subsidence problems in many large cities mainly cause from the excessive extraction of natural resources beneath the earth such as groundwater, petroleum, natural gas or mining. Bangkok and its vicinity the major land subsidence is groundwater extraction. According to the investigation on land subsidence due to groundwater exploitation of UNESCO (1975-1980), more

than 40 cities around the world which overused of groundwater have faced land subsidence problems. Some of that are 18 in the United States and 10 in Japan. Subsidence in U.S. that exceeding 1 meter occurs in 4 States: Texas, Arizona, Nevada and California. In California at San Joaquin Valley had maximum cumulative subsidence of 9 m (1926-1970) and subsidence area about 13,500 km² (Poland et al., 1975). In Japan, the subsidence area has reached 40 places mostly due to groundwater withdrawal. In Tokyo and Osaka had subsidence area about 2,420 km² and 570 km² and maximum cumulative subsidence 4.6 m. (1900-1975) and 2.5 m. (1935-1968) respectively (Yamamoto, 1977). Mexico City is one of the serious subsidence areas in the world. The entire metropolitan area has subsided more than 3 m and the maximum subsidence has reached 9 m (1891-1978) (Figueroa Vega, 1975; Premchitt, 1978). Also, the others are Shanghai and Taipei in China, Po Delta in Italy, Wairakei in New Zealand, London in UK, etc.

In Bangkok, land subsidence problem due to excessive deep well pumping has been periodically researched and reported by many researchers, e.g. Cox (1968), Pianchareon (1976), Premchitt (1978), AIT (1981), Ramnarong (1983), Ramnarong et al. (1998), Nutalaya et al. (1989), JICA (1995), Phienwej (1995, 1999), Phienwej et al. (2005), Giao (1997), Nguyen (1999), DMR (2000), UNEP (2001), DGR (2004). Most of the subsidence in Bangkok area probably occurred after 1960, due to extensive exploitation of groundwater. During 1978-1984, the maximum subsidence rate was more than 10 cm/year observed in the eastern part of Bangkok, including Bang Na, Phra Kanong, Hua Mark, Bang Kapi, Lad Phrao and Bang Khen. The total subsidence in these areas was found about 240 cm. till 2003. In Central Bangkok, the average subsidence rate was 5-10 cm/year during 1978-1984 to the total subsidence of 100-140 cm. in 2003. On the west bank of the Chao Phraya River (Thonburi) and the northern part of Bangkok from the Bang Khen area, the subsidence rate was very small as corresponding to slow withdrawal rate. The average rate was less than 5 cm/year during 1978-1984 and the total subsidence was about 20-70 cm. in 2003.

The recent report showed that land subsidence situation has been improved lately due to the effect of Groundwater Act B.E. 2520 and B.E. 2525. Subsidence rate in some areas even showed swelling. But land subsidence in the suburbs has still occurred with the constant rate about 3 cm/year. The prediction of land subsidence due to groundwater withdrawal have been studied by some researchers, e.g. Premchitt (1978), JICA (1995), Giao (1997), Nguyen (1999), DGR (2004), Sutham and Warakorn (2006, 2009), DGR (2009). By assuming several water pumping scenarios, the results were reported on the prediction of land subsidence permissibly withdrawn from aquifers. But the field characteristic of groundwater level change and settlement has never been reported before. The relation can be used for the administration and management of groundwater pumping in each aquifer. This relation will be name as “**Characteristic of Aquifer Drawdown and Settlement** or **CADS**”. This paper will describe the concept and the advantages of CADS, including the usage for prediction the future subsidence and groundwater management.

HYDROGEOLOGY

Bangkok and its suburbs are situated on the flood plain and delta of the Chao Phraya River which covered the Lower Central Plain of Thailand. The plain, also known as the Chao Phraya Basin, extends about 200 km. from North to South and about 150 km. from East to West. From electrical logs of groundwater wells, the Department of Mineral Resources (DMR) identified eight aquifers within 600 m. depth as follows:

- (1) Bangkok Aquifer (BK, 50 m. zone);

- (2) Phra Pradaeng Aquifer (PD, 100 m. zone);
- (3) Nakhon Luang Aquifer (NL, 150 m. zone);
- (4) Nontha Buri Aquifer (NB, 200 m. zone);
- (5) Sam Khok Aquifer (SK, 300 m. zone);
- (6) Phaya Thai Aquifer (PT, 350 m. zone);
- (7) Thon Buri Aquifer (TB, 450 m. zone);
- (8) Pak Nam Aquifer (PN, 550 m. zone)

A typical hydrogeology profile for North-South is showed in Figure 1. The aquifers consist mainly of sand and gravel separated by clay layers and they generally extend the full width and length of the plain. Most wells in Bangkok and its suburbs penetrated PD, NL and NB since they are highly productive of relatively excellent water quality. The BK gives saline water whereas SK and PT are less feasible due to their greater depths and water of inferior quality. The TB and PN have been proved to yield fresh water but have been tapped by only few wells (Nguyen, 1999).

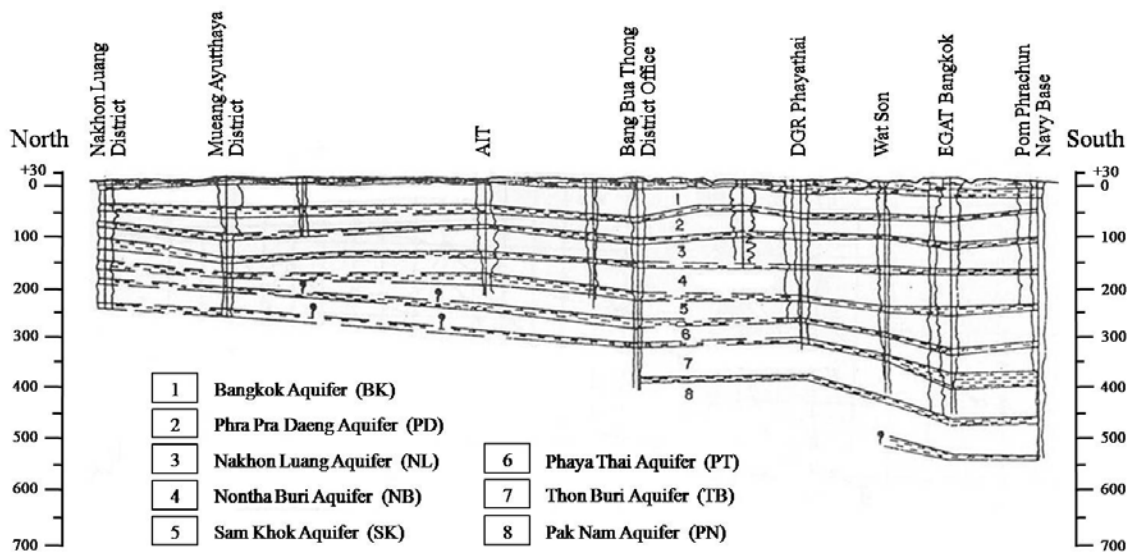


Figure 1: Typical hydrogeology profile for North-South of the Chao Phraya Basin. (Modified after Pianchareon, 1976)

SUBSIDENCE BY GROUNDWATER PUMPING

Subsidence of saturated soil may be occurred by increase in external load or lowering of groundwater level. Both of them can produce the excess pore water pressure and the consolidation process will progress in the soil. Figure 2 showed the mechanism of subsidence due to lowering of groundwater level.

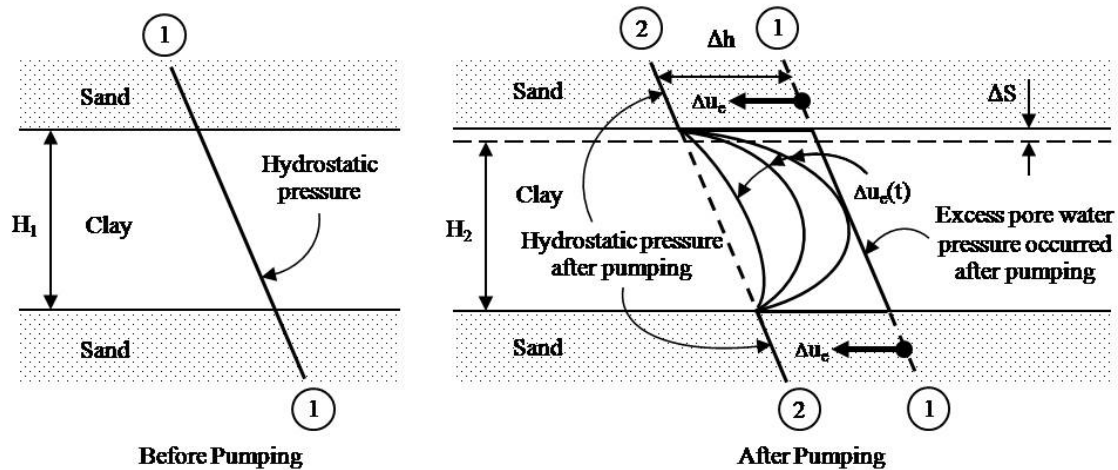


Figure 2: Mechanism of subsidence due to the lowering of groundwater level

In the Figure 2, when groundwater level is lowered by pumping, the pore water pressure in the sand is decreased immediately. But in the clay layer, the pore water pressure cannot dissipate quickly because of its low permeability. The excess pore water pressure is still retained in the soil and gradually decreases. The excess pore water pressure will be dissipated with time and resulting in settlement of clay layer. The settlement of clay (ΔS) will depend primary on the lowering of groundwater pumping but it depend also on the properties of soil such as elapsed time, thickness of clay layer, void ratio, OCR, compression index, coefficient of consolidation etc.

FACTS FROM GROUNDWATER LEVEL OBSERVATION

According to Figure 2, the settlement relate to decreasing in groundwater level in aquifer and consolidation in clay layers. Considering the relationship between the lowering of groundwater level and the corresponding settlement of soil in the same aquifer, we shall obtain a new relation which is named the **Characteristic of Aquifer Drawdown and Settlement** or **CADS**. The ratio between settlement change (ΔS) and groundwater change (Δh) is called CADS ratio. The CADS plotting can be divided in 4 stages. Figure 4, 5, 6 and 7 shows examples of the CADS in each stage which are some of all 276 wells from 110 stations as showed in Figure 3.

On the first stage, the CADS line tends to increase from left to right as showed in Figure 4. It is the stage of settlement increasing as direct proportion to the lowering of groundwater level. This stage is usually resulted from continuous pumping and steady settlement occurring. Although the process has the lag-time from soil consolidation in clay layer, it is considered to be included in the slope characteristic of CADS ratio.

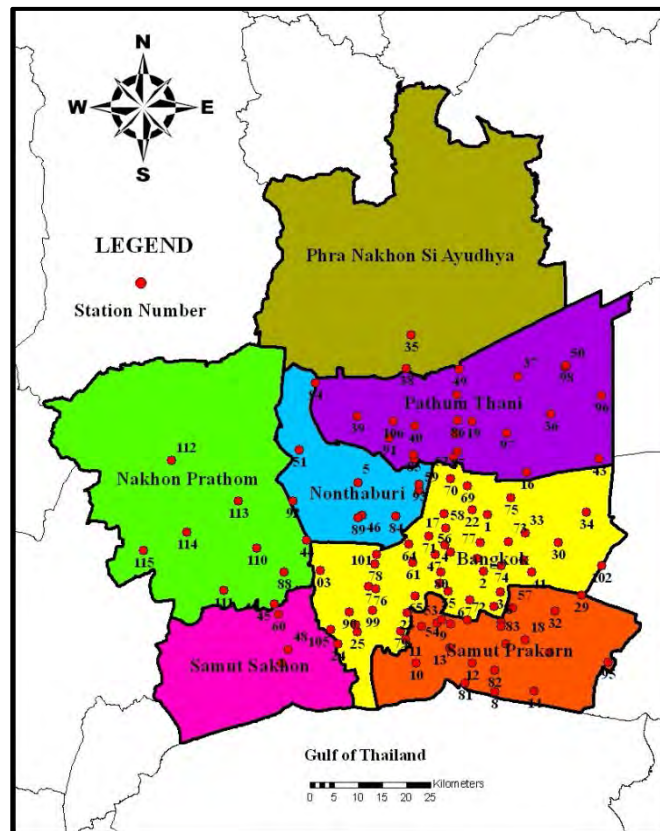


Figure 3: Study area and station locations

The inverse slope (CADS Ratio) or $\left(\frac{\Delta S}{\Delta h}\right)$ in the Figure 4 is defined as the rate of increasing of settlement in centimeter per 1 meter of decreasing in groundwater level. It can be used to express the areas which are sensitive to groundwater pumping.

Second stage is the duration of increase in groundwater level due to stop pumping or groundwater recovery. But the settlement still continues due to lag-time of consolidation process in the clay. Although the groundwater level is rising but it is not enough to recover the excess pore water pressure which has remained in the soil from the first stage. Therefore the consolidation process still proceeded and the settlement continued. The CADS line is declined as showed in Figure 5.

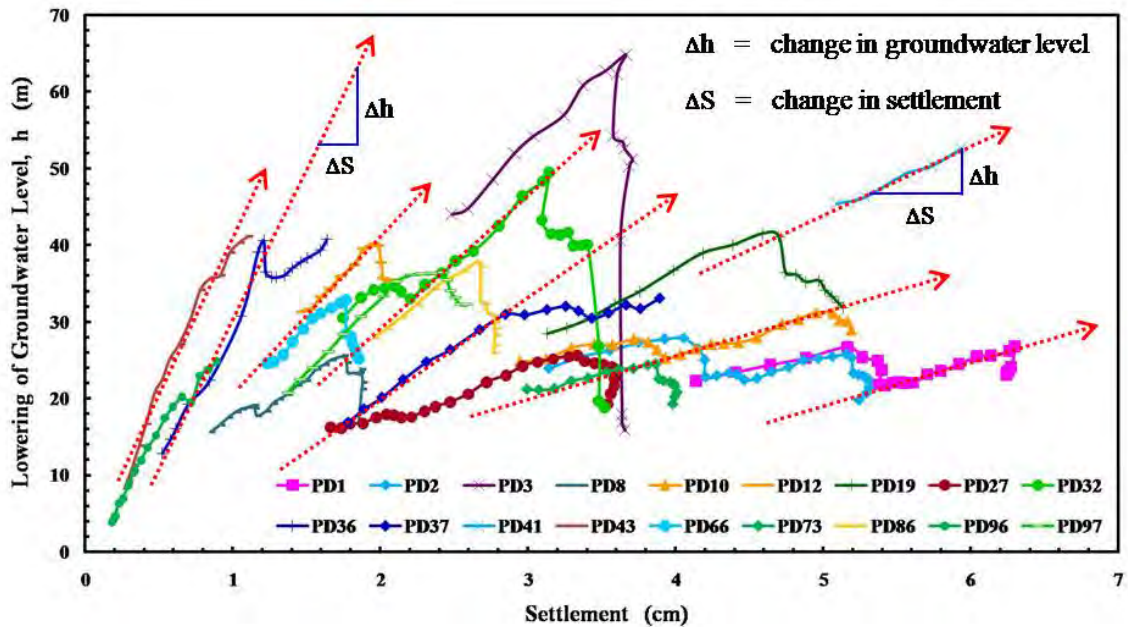


Figure 4: The increasing lines in the first stage of CADS

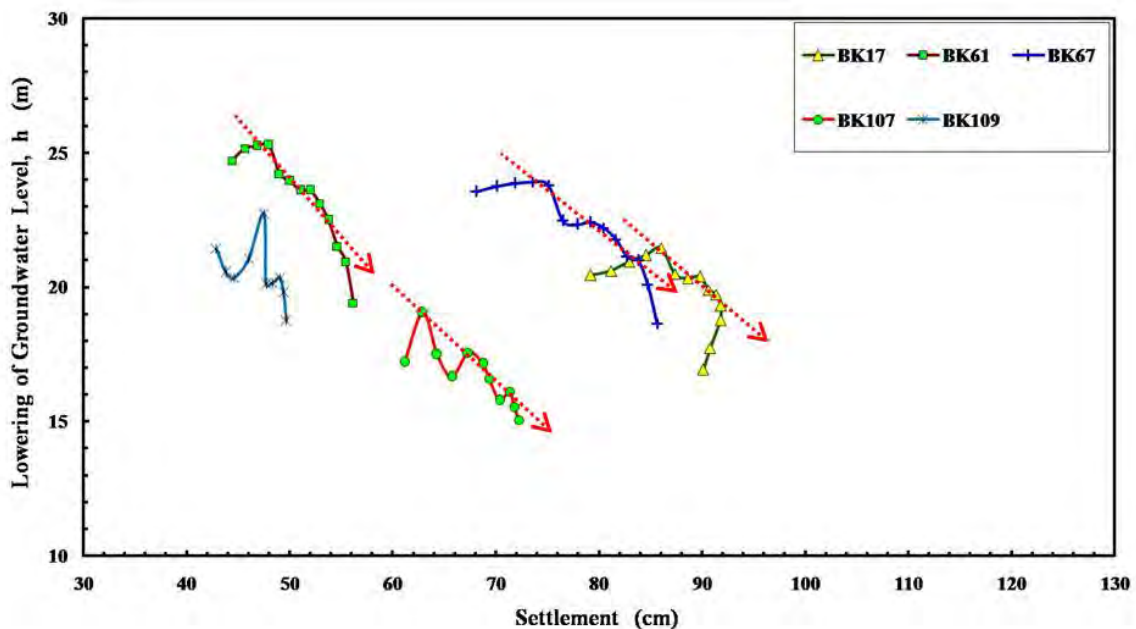


Figure 5: Delay Settlement in the second stage of CADS

Third stage is the duration of increase in groundwater level which is continued from the second duration. The settlement is closed to zero because the rising of artesian head can equilibrate to the consolidation process in the soil layer. The increase in aquifer water pressure can compensate the outer excess pore pressure but not penetrate the whole thickness of soil layer. Resulting the total consolidation of the whole aquitard close to zero. The CADS is closed to a vertical line as showed in Figure 6.

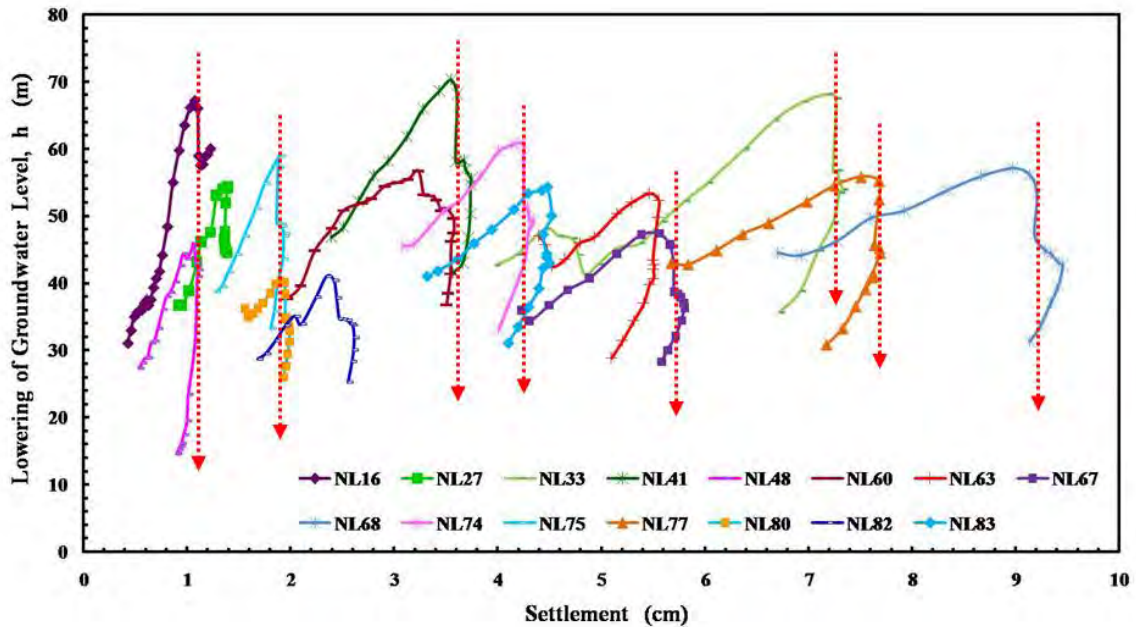


Figure 6: Zero Settlement in the third stage of CADS

Finally, the Settlement Recovery stage is the duration that the aquitard layer is swelled by the continuation of increase in groundwater level in the aquifer. The negative excess pore water pressure causes swelling of clay layer. The CADS lines are declined to the left as showed in Figure 7.

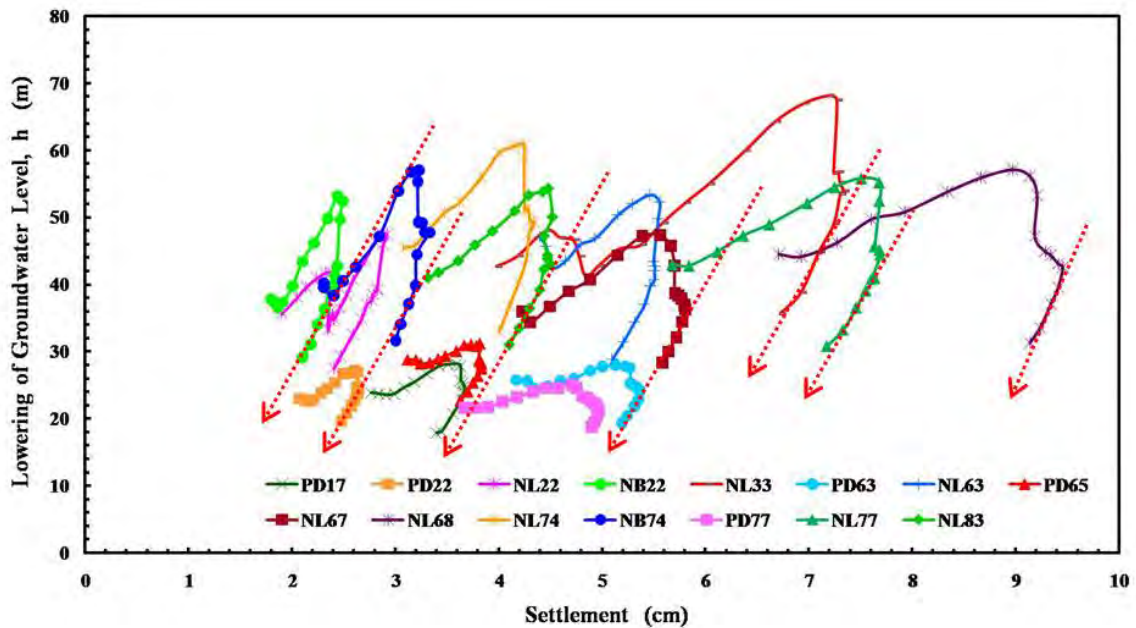


Figure 7: The Settlement Recovery in the fourth stage of CADS

APPLICATION OF CADS FOR GROUNDWATER MONITORING

The CADS lines represent the 4 stages of aquifer settlements. They are **Increase Settlement**, **Delay Settlement**, **Zero Settlement** and **Settlement Recovery** as summarized in Figure 8. The CADS pattern on each location and each aquifer can be in any stages and reflecting the advancement of groundwater usages. For the first stage, the aquifer is in active pumping stage and the soil is during increase in settlement. Something like that, if the final stage of CADS shows the 2nd, the 3rd or the 4th stage, it means that the aquifer is during decrease in pumping or rising of groundwater level and the soil is during decrease in the settlement or recovery. Thus the CADS can be used for administration and management of groundwater pumping in each aquifer when it is in the critical situation of the settlement.

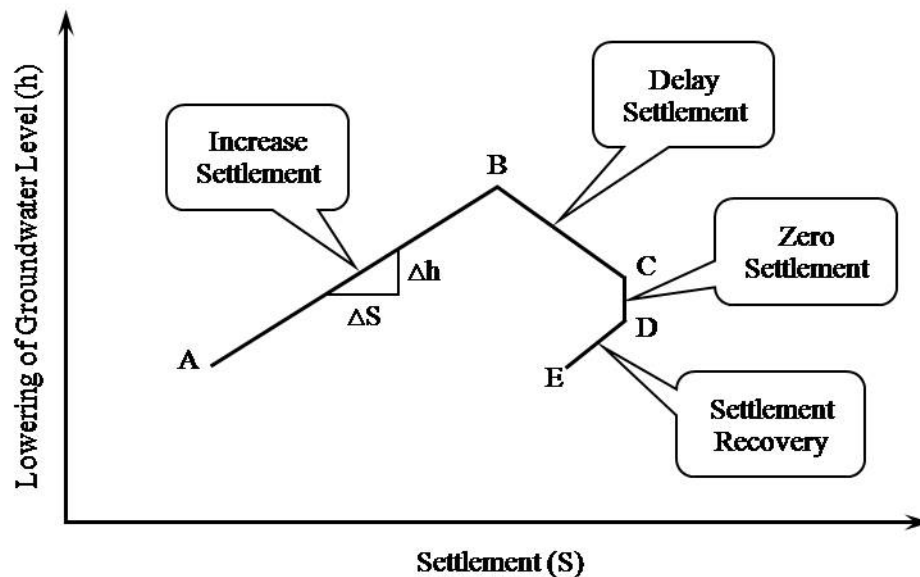


Figure 8: A Typical Form of the CADS

Figure 9 shows the stages of settlement of PD, NL and NB aquifers in the study area. The result showed that most of the center of study area has been in the Zero Settlement and Settlement Recovery stages. This means the settlement problem in the area which occurred for more than 40 years has been improved. It was the result of the implemented measures of groundwater management by DGR such as the Groundwater Act B.E. 2520, amended B.E. 2535 and amended B.E. 2546; the Cabinet Resolutions B.E. 2526 and B.E. 2538; and DMR's Announcement B.E. 2528 and B.E. 2537. But the east and the west of study area which were in the Increase Settlement and Delay Settlement stage have to be watched out. They should be strict implemented the measures of groundwater management especially in NB aquifer.

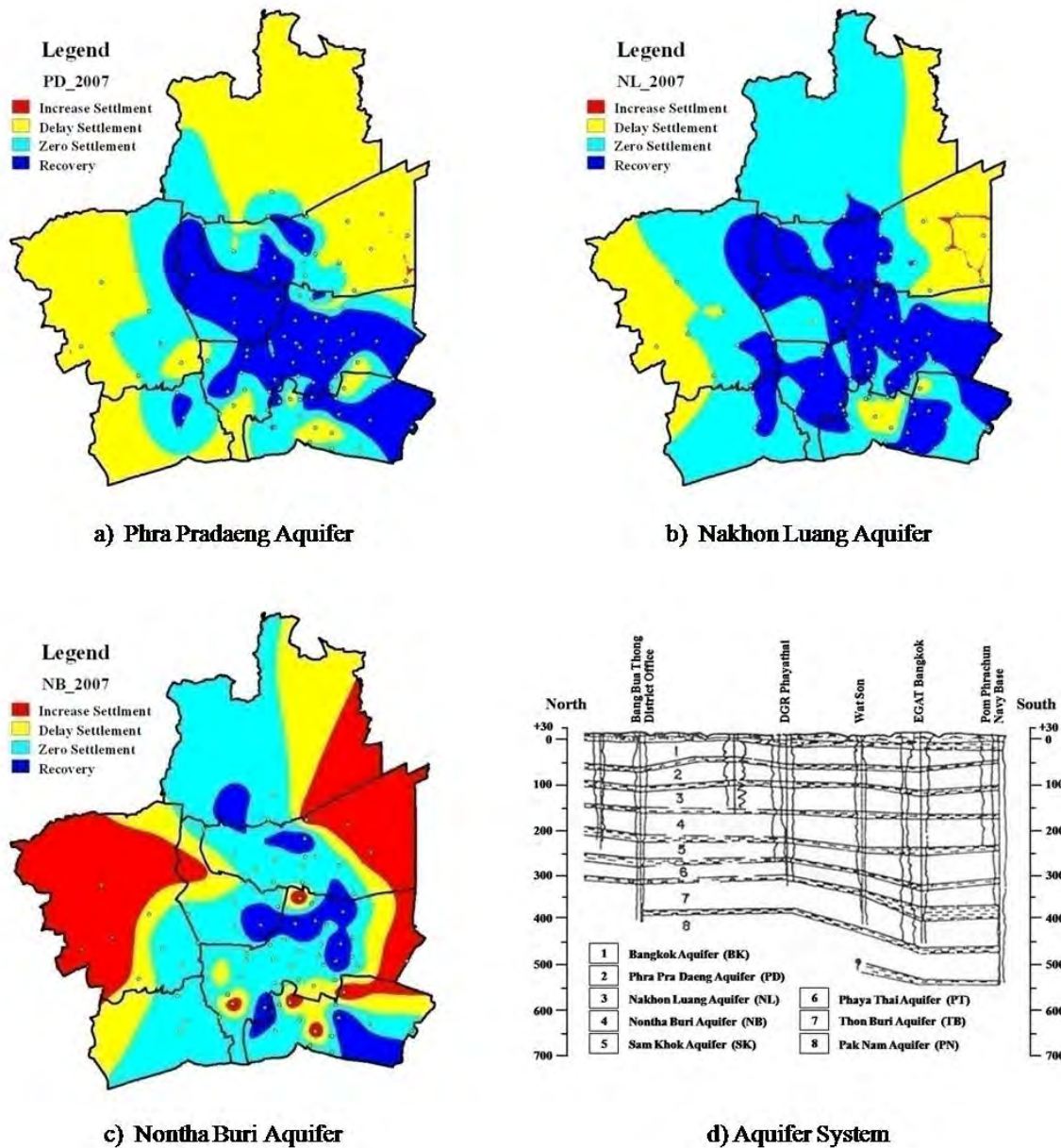


Figure 9: Stages of settlement of PD, NL, and NB aquifers in study area at year 2007

Otherwise, the CADS can be used to express the areas which are sensitive to the settlement. The inverse slope of the 1st stage ($\frac{\Delta S}{\Delta h}$) can be defined as the rate of increase in settlement per 1 meter of decrease in groundwater level which can be called as the sensitivity of settlement. Figure 10 shows the sensitivity of settlement area of PD, NL and NB aquifers. The results showed that the maximum sensitivity have two spots which is about 0.5 cm/year in PD aquifer at Amphoe Bang Phli, Samut Prakan Province and in NL aquifer at Amphoe Mueang, Samut Sakhon Province. Thus, the amount of groundwater pumping should be very strict controlled in these two areas in order to prevent the critical settlement.

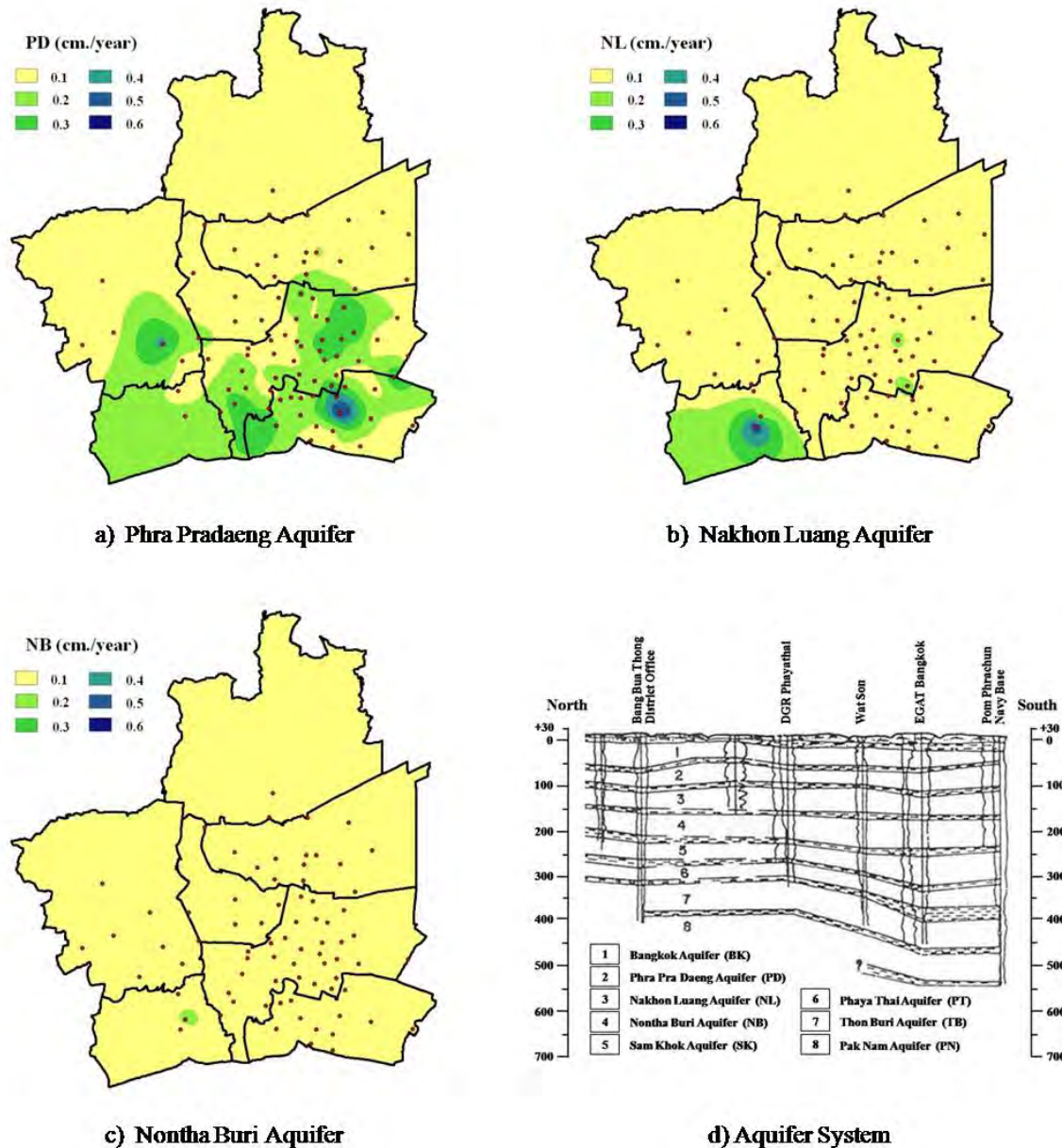


Figure 10: The sensitivity of settlement area of PD, NL, and NB aquifers

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