# Construction of subsurface dams and their impact on the environment

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**Abstract:** In Japan the Miyakojima national irrigation project consisting of two subsurface dams which store 20,000,000m$^3$ of groundwater in a limestone aquifer and draw up 50,000m$^3$ per day through 147 tube wells, was completed in 2001. This paper examines the arrangement of the pumping wells and evaluates influence of the subsurface dams on nitrogen contamination.

**Key words:** Subsurface dam, Nitrogen contamination, Limestone, Permeability, Groundwater

## Introduction

A subsurface dam is a facility that stores groundwater in the pores of the strata to enable its sustainable use. It has many merits for example, unlike a surface dam, it does not submerge land to store water and there is no danger of breaching disasters. The surface area can be used in the same way before and after the construction of the subsurface dam.

A subsurface dam allows the development of water resources in regions where the construction of surface dams is difficult due to geological conditions, and groundwater cannot be used in the current state. It is composed of a cut-off wall by which the groundwater flow is dammed or intrusion of the seawater is prevented, and facilities (wells, intake shaft and pumps) that draw up the stored groundwater. Since the utilization of stored groundwater in a subsurface dam requires pumping, operating costs are different from those of a surface dam.

In Japan, the construction of Miyakojima subsurface dams which store 20,000,000 m$^3$ of groundwater and draw up 50,000 m$^3$ per day with 147 tube wells, was completed, and some subsurface dams are being planned and constructed for irrigation in the Ryukyu and Amami Islands in the southwest of Japan (Nagata, 1993). Miyakojima Island, which is located about 2,000 km southwest of Tokyo in Japan, belongs to the subtropical zone with annual average temperature of 23 °C, humidity of 80 %, and precipitation of 2,200 mm (Figure 1). It is a relatively flat plateau with a low elevation (the highest elevation of the Island is 113 m above sea level) and consists of elevated limestone. About 57 % of the total land area of the island is used for agriculture. Field crops and animal husbandry products account for 82 % and 18 % respectively, of agricultural production. Sugar cane and tobacco are the main field crops. The island consists of Quaternary Ryukyu limestone with a high permeability and basement mudstone of the Tertiary Shimajiri groups. Ryukyu limestone is covered with a lateritic clay soil of 0.5-1 m in thickness. The effective porosity of Ryukyu limestone is about 10 %. Many parallel faults oriented from northwest to southeast are distributed throughout the island. The geological structure shows cuesta inclined toward the west. The base-

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ment forms several underground valley-shaped structures between these faults. Such geological and hydrological conditions are suitable for the construction of subsurface dams because groundwater flow can be easily dammed by cut-off walls in these valleys (Fig. 1). The Japanese government started the irrigation project with construction of two subsurface dams, (Sunagawa and Fukuzato), to develop the groundwater resource for agriculture in

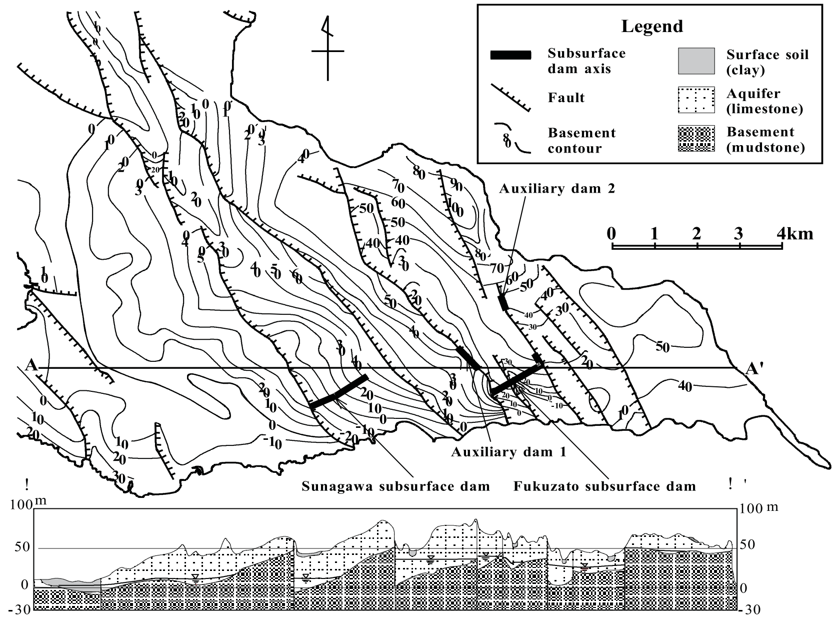


**Figure 1.** Geological section and basement contour map of the study area

Miyakojima Island in 1987. The total capacity of these two dams is about 20,000,000 m$^3$, making this one of the biggest subsurface dam systems in the world. Table 1 shows specifics of the two subsurface dams. The project was completed in 2001 and the two dams are fully recharged now. The cut-off walls were built with the In-situ Churning Method. The groundwater is drawn up by 147 tube wells and stored in farm ponds (water tanks), until it is supplied through the pipelines systems that serve the entire island.

**Table 1.** Specifics of subsurface dams

| | Sunagawa Dam | Fukuzato Dam | | |
|---|---|---|---|---|
| | Main Dam | Main Dam | Auxiliary Dam 1 | Auxiliary Dam 2 |
| Max dam height | 50.0 m | 27.0 m | 21.0 m | 6.0 m |
| Dam length | 1,677 m | 1,790 m | 786 m | 332 m |
| Elevation of crest | 31.0 m | 46.0 m | 46.0 m | 46.0 m |
| Basin area | 7.2 km$^2$ | 12.4 km$^2$ | | |
| Total Capacity | 9,500,000 m$^3$ | 10,500,000 m$^3$ | | |

## METHOD OF DESIGN FOR MANY PUMPING WELLS ARRANGEMENT

The caves of several cm in diameter have formed in Ryukyu limestone by the infiltration of rain. Once the chain of caves being to conduct water with soil into the deep limestone, the intruded soil called "infiltrated clay" closes the pore of the limestone and decreasing its hydraulic conductivity. The decreasing rate of the hydraulic conductivity of limestone fluctuates from 1/10 to 1/100 of the hydraulic conductivity of the original limestone depending on the volume of the infiltrated clay. Therefore, it is not unusual for a well with production capacity of 100 $m^3$ per day to be only a few meters away from a well producing 2,000 $m^3$ of water per day. A production volume of 2,000 $m^3$ per day in each well is required to supply the irrigated fields. If the wells are arranged without regard to the infiltrated clay, the designed intake of water may be impossible. We studied the relationship between the infiltrated clay content and the hydraulic conductivity from the data of borings and pumping tests obtained at 48 points in the Sunagawa subsurface dam catchment area. The degree of clay infiltration in the limestone pores was derived by observing the boring core for each point. The pumping tests for hydraulic conductivity were carried out at the same point. Fig. 2 shows the relation between the infiltrated clay content and the hydraulic conductivity calculated from pumping test data from each investigation point in the Sunagawa subsurface dam catchment area. The relation shows a negative correlation, and the correlation coefficient is 0.69. The infiltrated clay content distribution maps were drawn from the observation of core boring samples, and we converted the infiltrated clay content into the hydraulic conductivity according to the expression shown in Fig. 2. We analyzed the groundwater flow by numerical simulation based on this permeability distribution, and determined the arrangement of the wells based on the results. All the wells that had been positioned by this method could provide at least 2,000 $m^3$ of water per day.

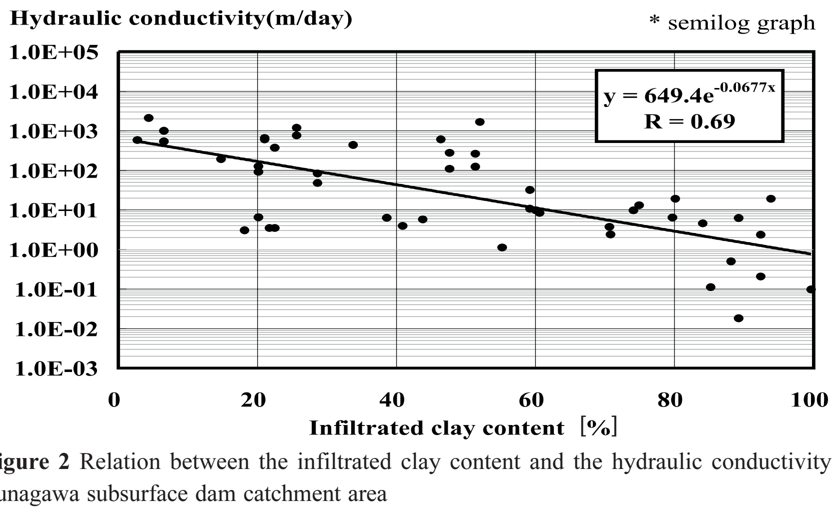


**Figure 2** Relation between the infiltrated clay content and the hydraulic conductivity in Sunagawa subsurface dam catchment area

## Evaluation of influence of subsurface dam on nitrate contamination

The subsurface dam in Miyakojima Island has artificially changed the groundwater level and groundwater flow. It was difficult to forecast the influence of underground dams on the groundwater environment because these were the allowable the first large-scale underground dams in the world. Before the construction of subsurface dams, the concentration of nitrate nitrogen has been about 10mg/l, the limit for drinking water in Japan, due to the overuse of fertilizer in sugarcane fields. Groundwater quality, especially nitrate contamination, is one of the most serious concerns to people in Miyakojima Island. Long term monitoring of groundwater at the typical observation wells in the catchment area has been done since 1988. Fig. 3 shows the fluctuation of the concentration of nitrate nitrogen in groundwater in the catchment area of the Sunagawa subsurface dam. The cut-off wall was completed in 1993, and the dam was filled with groundwater in 1995. The groundwater nitrate nitrogen concentration decreased slightly until 1994. Since then, it has been mostly stable with only about 2 mg/l fluctuation. This tendency is same in the catchment area of Fukuzato subsurface dam. These results show that the impact of the cut-off walls on the underground environment is too small to influence the nitrate concentration in groundwater. We think that the reason is that the amount of fertilizer use has not increased because the cultivation area of sugarcane has not increased. The stored water was drawn up and used after the subsurface dam had been fully recharged with water, therefore, stored water of subsurface dam was refreshed.

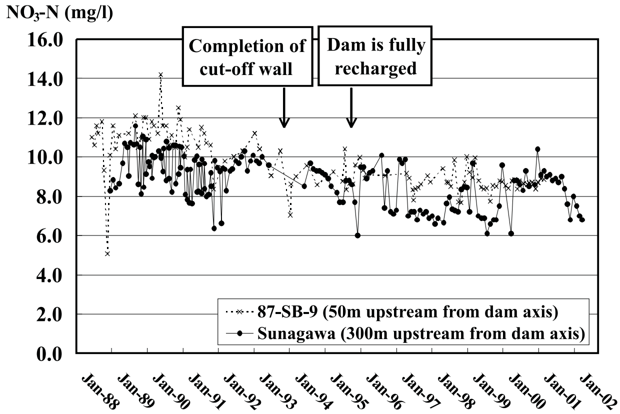


**Figure 3.** Fluctuation of the concentration of $NO_3$-N in groundwater at the catchment area of Sunagawa subsurface dam

## CONCLUSIONS

We did two investigations for the Miyakojima Island subsurface dam project. The first concerned the distribution of a low permeability zone of limestone. This was due to infiltrated clay. After we verified the relation between the infiltrated clay content and the hydraulic conductivity, we were able to arrange the wells appropriately. The second concerned the impact of subsurface dam on groundwater nitrate concentration. The results of more than ten years of observation show that the impact of the cut-off walls on the underground environment is too small to influence the nitrate concentration in groundwater. However, continuous observation of the groundwater quality is required to confirm whether or not this trend continues.

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