# TEMPERATURE DISTRIBUTION AND SEASONAL HEAT FLUX CHANGE IN SENDAI PLAIN

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## 1. INTRODUCTION

Aquifer temperature is sensitive to changes in groundwater flow patterns, because groundwater convection significantly contributes to transport the heat in the subsurface layer. On the other way, thermal effects cause significant changes in hydraulic conductivity since density and viscosity of water are temperature dependents (Janes 1990, Constantz et al.1994, Constantz and Thomas 1997 and Constantz 1998). Therefore, studying the changes of aquifer temperature distribution under the seasonal changes of climatic and groundwater flow might be important to understand the response of aquifer thermal regime on global climate change. This study therefore accounts the role of groundwater flow on temperature distribution in Sendai plain and estimates the seasonal heat flux changes.

## .2. THEORY

Satllman (1960) derived a partial differential equation for conductive and groundwater convective heat transfer.

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2}=\frac{C_w\rho_w}{K_{ws}}\left[\frac{\partial(v_xT)}{\partial x}+\frac{\partial(v_zT)}{\partial z}\right]+\frac{C_{ws}\rho_{ws}}{K_{ws}}\frac{\partial T}{\partial t} \quad (1)$$

Where, $T$ is the temperature, $t$ is the time, $\rho_w$ and $C_w$ are the density and specific heat of the water, $\rho_{ws}$ and $C_{ws}$ are the density and specific heat of the porous medium, $K_{ws}$ is the thermal conductivity, and $v_x$ and $v_z$ are the velocity components in $x$ and $z$ directions. An analytical solution for Satllman's equation for two-dimensional temperature distribution, under the steady state groundwater flow was presented by Domenico and Palciauskas (1973). In their solution, when the groundwater potential is in the form of

$$h(x,z)=A-[B\cosh(\pi z/L)/\cosh(\pi z_0/L)]\cos\frac{\pi x}{L} \quad (2)$$

where $L$ is the distance between the recharge and the discharge area of the basin, $z_0$ is the groundwater potential at a reference depth (MSL), and $A$ and $B$ are constants, corresponding temperature distribution was obtained as,

$$T(x,z)=T_1+T_0'(z-z_0)-(T_0'KB/2\alpha)[\cos(\pi x/L)/\cosh(\pi z_0/L)]\times \\ \{(z_0-z)\cosh(\pi z/L)+(L/\pi)[\sinh(\pi(z-z_0)/L)/\cosh(\pi z_0/L)]\} \quad (3)$$

Here, $T_1$ is the constant temperature at the upper most point of the water table, $T_0'$ is the constant temperature gradient, $\alpha(=k/\rho c)$ is the thermal diffusivity and $K$ is the hydraulic conductivity. When the appropriate temperature distribution is known, corresponding heat flux can be estimated from the Fourier's law of heat conduction.

$$q_t=-k\frac{\Delta t}{\Delta x} \quad (4)$$

## 3. METHODOLOGY

Area about 500 km$^2$, including the Natori and Nanakita rivers was selected. There are four water level observations stations (5-60m depth) are located within the area. Temperature loggers with 0.2$^0$C accuracy were used to measure the continuous one hour groundwater temperature at selected depths up to 60m in three wells. Moreover, one hour groundwater levels were also taken in all wells throughout the simulation period.

MODFLOW groundwater model was used for the numerical simulation of groundwater flow. 250m × 250m grid space was selected. Minimum and maximum water levels during four month time period (0.92m and 1.77m in W1, 2.54m and

3.71m in W2 and 2.69m and 4.22m in the W3) were considered to estimate the heat flux change during two events. Simulated results were verified by the daily averaged observed water level records. Simulated groundwater profiles along the each well towards the sea direction were matched with the Domenico and Palciauskas equation for groundwater potential to obtain the unknowns of *A* and *B*. Those unknowns were used in the equation 3 and 4 to obtain the corresponding temperature distribution and seasonal heat flux change in Sendai plain.

## 4. RESULTS AND DISCUSSION

Ground water simulations showed good agreement with the observed water level records and the Domenico and Palciauskas equation for groundwater potential (Fig.1 a). It also displays better match with the observed temperature records which confirms the presence of groundwater convection and importance of accounting the water flow effect in heat distribution estimations.

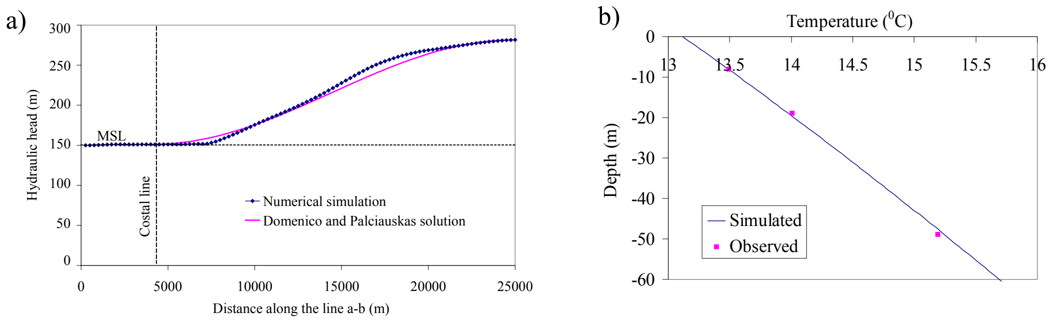


Fig. 1: water level and temperature profiles at the W1 in event 1

Constrained parameters by matching the simulated water level profiles and Domenico and Palciauskas equation in all the wells and obtained results are shown in Table 1.

Table 01: Constrained parameters

| | Minimum water level | | | Maximum Water level | | |
|---|---|---|---|---|---|---|
| | W1 | W2 | W3 | W1 | W2 | W3 |
| *A* (m) | 216.30 | 219.1 | 217.1 | 215.95 | 217.8 | 215.9 |
| *B*(m) | 65.24 | 68.23 | 68.6 | 64.12 | 66.62 | 66.4 |
| *L*(km) | 21 | 19 | 18.5 | 21.25 | 19.50 | 18.75 |
| $z_0$(m) | 150 | 150 | 150 | 150 | 150 | 150 |
| $T_0'$($^0$Cm$^{-1}$) | 0.036 | 0.026 | 0.009 | 0.03 | 0.015 | 0.009 |
| Heat flux (mW/m$^2$) | 51.4 | 38.9 | 12.8 | 42.7 | 21.57 | 12.7 |

## 5. CONCLUSION

Seasonal heat flux change in Sendai plain was estimated using the MODFLOW numerical code and Domenico and Palciauskas analytical solution for the two dimensional temperature distributions. Maximum of 51.4 mW/m$^2$ heat flux was calculated and it was observed to be changed about 17% during four month time period. The heat transport model developed in this study was able to explain the heat exchange during the recharge and discharge events due to hydraulic head change. Results suggest that this method can be applied in the basin scale to evaluate the seasonal heat flux change associates with groundwater flow.

## REFERENCES

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