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Modeling groundwater level fluctuation in the tropical peatland areas under the effect of El Nino

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Abstract

This research aimed to model groundwater level (GWL) fluctuation in the tropical peatland areas under the effect of El Nino Southern Oscillation (ENSO). The focus of the study was the peatland area between Sebangau River and Kahayan River, Central Kalimantan Province – Indonesia. One-dimensional GWL model was developed using Excel in order to simulate the GWL fluctuation of 4 GWL observation wells which were Swtr2, Swtr3, Swtr4, and Swtr6. The model was calibrated for the dry season 2011 and, after that, was used to model GWL fluctuation in El Nino year of 1997 and 2002. The model showed very good performance in simulating GWL fluctuation of 4 observation wells in the dry season condition where the GWL were under the ground level elevation. The model indicated that in the El Nino years of 1997 and 2002, the GWL in the observed area in the dry season dropped significantly due to the absence of rainfall in the area. Based on the model, the fire risk in the tropical peatland areas can be measured and predicted

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Keywords: Groundwater fluctuation model; ENS; tropical peatland areas

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1. Introduction

El-Nino Southern Oscillation (ENSO) is a climate phenomenon that is associated with sea surface temperature anomalies in the waters of the Pacific Ocean. ENSO leads to changes in temperature and precipitation. In Indonesia ENSO caused drought in most parts of the regions. In the year 1997/1998 ENSO event has caused the most severe forest fires around the world including Indonesia. Based on

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research conducted by Bappenas and the Asian Developement Bank [1], widespread forest fires in Indonesia caused by ENSO events during the year reached 9.75 million ha [2].

Of the total area of forest burned, it was 1.46 million ha of peatlands that were scattered on the islands of Kalimantan (0.75 million ha), Papua (0.40 million ha) and Sumatra (0.31 million ha). Forest fire in the peatland areas is very important to note. Peat lands are the world largest carbon source. When the fire happened in the peat forest, organic carbon (C) becomes carbon dioxide (CO_2) and it will be released to the atmosphere in very large quantities and becoming green house gases as a fuel of global warming.

Changing peatlands into agricultural and residential areas will change the pattern of groundwater in the area of peat. Construction of drainage channels causes a drop in the groundwater in the peat soil. Furthermore, the decline in ground water will lead to increased risk of forest fires due to dry peat. Under these conditions, studying the behavior of groundwater in the peat in order to maintain a high water table and reduce the risk of forest fires is a very important thing to do. The best way to monitor the behavior of groundwater is to directly measure the groundwater in monitoring wells. However, cost and effort required to conduct monitoring of groundwater behavior in a long time with an adequate measurement point. There were limited numbers of groundwater parameters of peat swamp areas have been readily measured in the field [3]. Yet, research concerning the application of groundwater models to wetland hydrologic systems have been rarely undertaken, especially for tropical peat swamp areas, and only few publications have been found on this important subject [4].

An alternative method for predicting the effect of hydrological parameter on groundwater level (GWL) behavior in the wetland is by modeling the system. By modeling we hope to describe an event in the past based on a schematic description, theory, or phenomenon of a same system with different data. Therefore, this research aims to model GWL fluctuation in the peatland areas in the past. The focus of this research is to model GWL fluctuation under the effect of ENSO and investigate its relation to the risk of forest fire. The area of the study is the peatland area on the area between Sebangau River and Kahayan River. The area is located between coordinates of 114.01^o E, 2.28^o S and 114.09^o E, 2.37^o S. The area is known as the Block C of ex – Mega Rice Project area, in Central Kalimantan Province, Indonesia.

2. Methodology

2.1. Study site and data

Figure 1 showed the study area, the Block C of ex – Mega Rice Project area, in Central Kalimantan Province, Indonesia. In this area, in 1995, Indonesian Government launched a project called Mega Rice Project in Central Kalimantan. The launching of the project aimed to save the national food program by changing peatland areas into paddy field areas. However, in 1999 the government had stopped the project under the suggestion of several international foundation and some investigations carried out by the some government institutions. The main reason of the project discontinued was that the development of peatland areas would destroy the peatland environment and drain the water in the peatlands. Drainage of the peatswamps will lead to rapid decomposition of the organic carbon of the peat and to annual peat fires. This degradation has a devastating impact on the means of air pollution in South-east Asia and last but not least climate change as huge quantities of organic carbon becomes carbon dioxide. Emissions from degraded peatland areas will continue until all peat has disappeared [5]. A decade after the launching of the project, the areas became drained areas and turn to be abandoned forest areas. Nowadays, the project of peatland development changes into peatland restoration project in order to save peatland areas in Central Kalimantan. Some international organizations have been involved in the areas with aim to restore the peatland.

Groundwater level (GWL) for this research was measured using automatic gauge (OYO S&DL mini) installed in the wells by Center for International Cooperation in Sustainable Management of Tropical Peatland (CIMTROP) of Palangkaraya University, Indonesia and Center for Sustainability Science (CENSUS) of Hokkaido University, Japan. Daily GWL data was used for daily simulation in the modeling and was extracted from hourly GWL data that had been recorded between June and September 2011. In order to find the real fluctuation of GWL due to rainfall and evapotranspiration on the observed area, the GWL data used for simulation had to be the one which the elevation is under the elevation of ground level for every groundwater wells. In detail, the description of each well is presented in table 1 and figure 1.

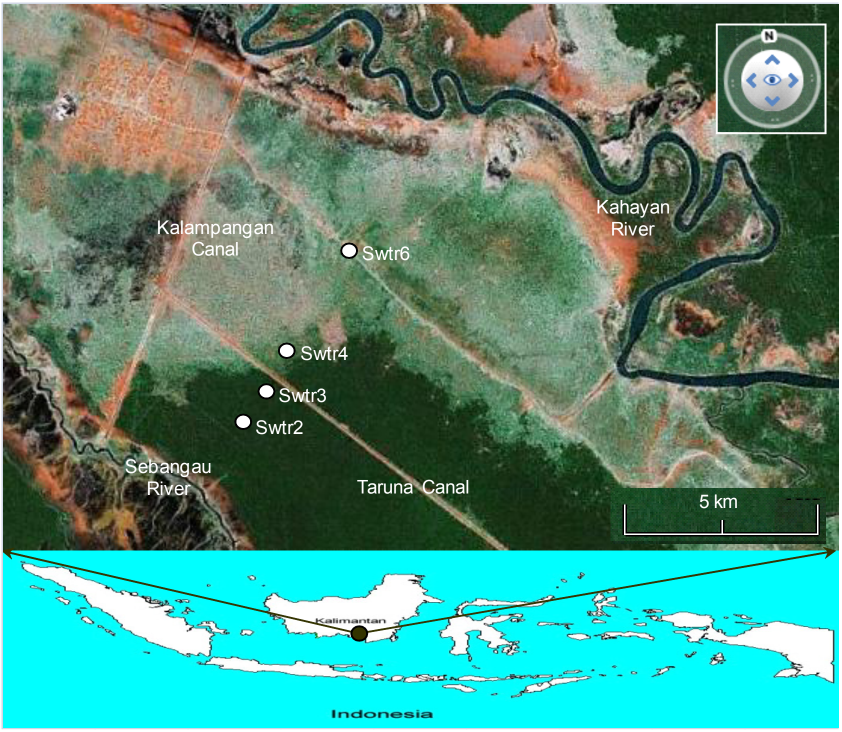

Fig. 1. Study site and groundwater observation wells location.

Table 1. Location of each well and its land cover

No.	Point	Latitude S	Longitude E	Ground level (m)	Vegetation	Starting date of simulation	Last date of simulation
1	Swtr2	2.3548	114.0297	19.81	Natural forest	6/1/2011	8/15/2011
2	Swtr3	2.3479	114.0361	20.16	Natural forest	7/1/2011	9/30/2011
3	Swtr4	2.3407	114.0428	19.31	Grassland	7/1/2011	9/30/2011
4	Swtr6	2.3212	114.0586	18.56	Grassland	7/1/2011	9/30/2011

Hydrological data used in this research was daily rainfall data and daily temperature data. Both types of data were obtained from the local hydrological station in the location of study.

2.2. Modeling procedures

One-dimensional GWL model was developed using Excel in order to simulate the GWL fluctuation of 4 GWL observation wells. The stations are Swtr2, Swtr3, Swtr4, and Swtr6. The water balance equation under specific time period (Δt) is expressed as [6]:

$$P = Q + E + \Delta S \tag{1}$$

where P is precipitation, Q is the sum of surface runoff, transpiration, interflow, and surface detention, E is evapotranspiration, ΔS is the change in storage of groundwater. When the calculation is only focused on the groundwater recharge process in the unsaturated and saturated zone, the value of Q can be neglected. It is because all component of Q are soil surface processes. For GWL fluctuation model for in this particular research, the water balance equation under specific time period (Δt) is expressed as:

$$\Delta h = (P-Q)/Sy - ETo.Kc/Sy \tag{2}$$

where Δh is the increase/decrease in GWL, ETo is reference evapotranspiration, Kc is crop coefficient, and Sy is specific yield of the soil.

The system of the GWL model can be illustrated in the Figure 2. Soil column in the figure 2 is considered uniform soil and *ho* is initial condition of GWL. Boundary condition of the system is that there is no flux from or to the right side, left side, and the bottom of the system. The top of the system is atmospheric boundary layer the area between ho and soil surface is considered unsaturated zone. Oppositely, the area below *ho* is saturated zone and the bottom of the system is impermeable area.

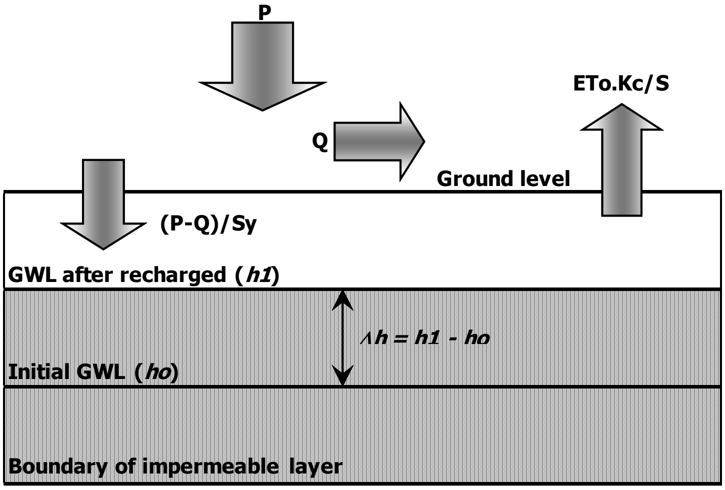

Fig. 2. Diagram showing the method of GWL fluctuation mechanism used in the model.

2.3. Evapotranspiration calculation

Based on the availability of the data, the Hargreaves method was used in this research for estimating *ETo*. The Hargereaves equation can be expressed as [7]:

$$ETo = 0.0023(T_{mean}+17.8)(T_{max}-T_{min})^{0.5}Ra \tag{3}$$

where *ETo* is the daily reference evapotranspiration (mm/day), T_{max} and T_{min} are the maximum and minimum daily temperatures, respectively ($^{\circ}$C), T_{mean} is the mean temperature ($^{\circ}$C) and *Ra* is the extraterrestrial radiation (MJm^2/day).

2.4. Model calibration and evaluation

The model was calibrated using GWL data recorded between June and September 2011. The calibration process is undertaken by adjusting C, Kc, and Sy parameter values into the best fit of the observed and calculated GWL. The best fit of the model is indicated by the highest value of the Nash-Sutcliffe Efficiency Index (η) for the simulation of all observed well. McCuen et al. [8] has demonstrated that the Nash-Sutcliffe Efficiency Index is comparable to the coefficient of determination (R^2) and its use is recommended for non-linear modeling problems [9]. This coefficient is defined as:

$$\eta = 1 - [\Sigma(x-y)^2/[\Sigma(y-y')^2] \tag{4}$$

where x is observed value, y is the calculated value, and y’ is the average of observed values. The η maximum value is 1.0, which means a perfect match of modeled data with the observed data. If the η value is equal to 0.0, the model predictions will be as accurate as the mean of the observed data.

3. Results and discussions

The value of Kc and Sy for the best fit of model for every data series of calibrated year is presented in table 2, and graphical presentation of model simulation results was given in the appendix A. The model showed very good performance in simulating GWL fluctuation of 4 observation wells in the dry season condition where the GWL were under the ground level elevation.

Table 2. The value of Kc and Sy for the best fit of model for every data series calibrated for year 2011

Site	Initial Q	Kc	Sy	η	R^2
Swtr2	0.74	0.75	0.40	0.92	0.92
Swtr3	0.74	0.53	0.30	0.86	0.86
Swtr4	0.10	0.59	0.38	0.81	0.81
Swtr6	0.14	0.60	0.40	0.87	0.87

The model, furthermore, was used to simulate the GWL for El Nino year of 1997 and 2002 for the period of July 1st to October 30th. The initial condition of GWL in every simulation was assumed equal to ground level. Graphical presentation of model simulation results was given in the appendix B and C.

There were several characteristics that can be identified from the condition of groundwater level on the area observed. The most prominent characteristic was that in the El Nino year position groundwater always below ground level for a period of more than 3 months. It is not too surprising because the amount of precipitation in the dry season of El Nino years was generally smaller than the ones in normal years. Rainfall greater than 10 mm were rare and this circumstance resulted in a negative water balance. Moreover, in 1997, the rainfall was more than 10 mm only happened twice in the period of the simulation and the distance events with more than 3 months. The graphs in the appendix B and C also showed that the GWL in the observation wells dropped significantly due to the absence of rainfall in the area. Ideally, to prevent the peatland area from the risk of peat fires, the water table cannot be more than 40 cm below the soil surface. If the groundwater level in tropical peat drops below 40 cm from the surface, the moisture content of the little humified top layer decreases drastically from about 0.90 cm^3/cm^3 at saturation to about 0.50 cm^3/cm^3 at a pressure head of −4 kPa. This situation will lead to peat fires because the fire spread quickly in dry peat soil [10][11][12][13].

Forest fires are an annual occurrence in Indonesia during the dry season. Most of the forest fires, both ordinary and peatland forest, caused by human activities in the context of land clearing or logging. But in recent years, forest fires caused by natural disasters such as droughts become an interesting topic to talk about. Especially after a major fire incident in the year 1997/1998, natural factors such as ENSO became a focus of the attention in the prevention and mitigation of global forest fires in Indonesia. El Nino in Indonesia can be monitored by continuous observation of sea surface temperature (SST) anomalies over central and east Equatorial Pacific several months before the event happens. The use of remote sensing data has been intensively undertaken to monitor SST anomalies in order to detect the event of El Nino globally in Indonesia [14].

Until now, monitoring and modeling of groundwater level in peat lands in Indonesia for the purpose of anticipating forest fires have not been implemented. In fact, an accurate modeling of groundwater for peatland may serve as an indication of the position GWL elevation. Furthermore, the possibility of peat fires can be detected based on the state of the GWL. Detection possibility of peatland fires via GWL model will also provide more detailed information about the status of a regional fire risk than global information obtained from satellites. There are three important things that should be available in the modeling of ground water in peatland. They are the rainfall data, temperature data, and GWL data. All must have good accuracy and a sustained period. Direct monitoring of the GWL in peatland areas may require a substantial investment. But the cost of the investment will be very small compared to the benefits of the land saved from the fire. However, forest fire in peatland is quite complex to be resolved. A technology or method cannot stand alone to handle this problem. The combination of technologies and methods, both technical and non-technical, is probably the most recommended way in the prevention and management of fires in peatland area in Indonesia.

4. Conclusion

The ENSO has significant effect on GWL and fire risk in the peatland. The fire risk in the tropical peatland areas can be measured and predicted based on GWL fluctuation model. The model in this study showed that in the years of El Nino, the elevation of groundwater in the area observed decreased dramatically, especially in the dry season. The decline was more than 40 cm below the soil surface. This means the possibility of a peat fire danger is high for this area. In the future, this kind of models are expected to be used to determine the level of fire hazard possibility of peatland and can serve as a reference in determining the strategy in handling of peatland fires in Indonesia.

5. Acknowledgement

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References

[1] BAPPENAS-ADB. Causes, Extent, Impact and Costs of 1997/1998 Fires and Drought. Final report, Annex 1 and 2. Planning for Fire Prevention and Drought Management Project. Asian Development Bank TA 2999-INO. Jakarta, National Development Planning Agency (BAPPENAS), and Asian Development Bank; 1999.

[2] Tacconi L, *Forest fire in Indonesia: cause, cost, policy implication*. CIFOR Occasional Paper No. 38; 2003. Available from: www.cifor.org/publications/pdf_files/OccPapers/OP-038.pdf [Accessed August 2012].

[3] Schot PP, Pieber SM. Spatial and temporal variations in shallow wetland groundwater quality. *Journal of Hydrology* 2012, **422**: 43-52.

[4] Boswell JS, Olyphant GA. Modeling the hydrologic response of groundwater dominated wetlands to transient boundary conditions: Implications for wetland restoration. *Journal of Hydrology* 2007, **332**: 467–476.

[5] Wetland International. The Central Kalimantan Peatlands Project (CKPP); 2007. Article retrieved from website: http://ckpp.wetlands.org/ [Accessed August 2012].

[6] Maréchal JC, Dewandel B, Ahmed S, Galeazzi L, Zaidi FK. Combined estimation of specific yield and natural recharge in semi-arid groundwater basin with irrigated agriculture. *Journal of Hydrology* 2006, **329**: 281-293.

[7] Droogers P, Allen RG. Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst.* 2002, **16**: 33–45.

[8] McCuen RH, Knight Z, Cutter AG. Evaluation of the Nash–Sutcliffe Efficiency Index. *Journal of Hydrologic Engineering* 2006, **11(6)**: 597–602.

[9] Torres AF, Walker WR, McKeena M. Forecasting daily potential evapotranspiration using machine learning and limited climatic data. *Agricultural Water Management* 2011, **98**: 553–562.

[10] Wösten JHM, Clymans E, Page SE, Rieley JO, Limin SH. Peat–water interrelationships in a tropical Peatland ecosystem in Southeast Asia. *Catena* 2008, **73**; 212–224.

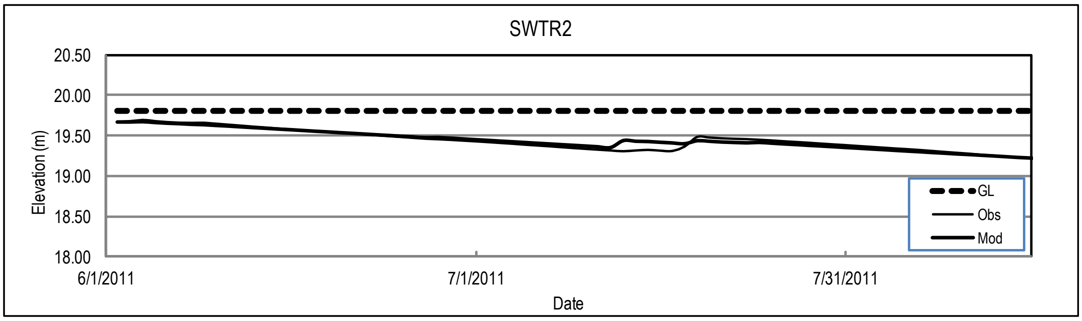
[11] Rieley JO, and Page SE. *Wise Use of Tropical Peatlands: focus on Southeast Asia*. Alterra, Wageningen University and the EU INCO STRAPEAT and RESTORPEAT Partnerships, Wageningen, the Netherlands; 2005.

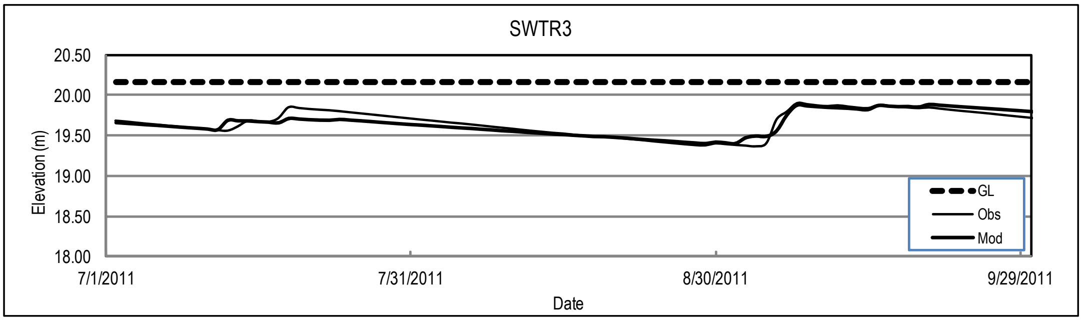
[12] Takahashi H, Usup A, Hayasaka H, Limin SH. *Estimation of ground water levels in a peat swamp forest as an index of peat/forest fire*. Proceedings of the International Symposium on Land Management and Biodiversity in Southeast Asia. Bali, Indonesia, 17-20 September 2002.

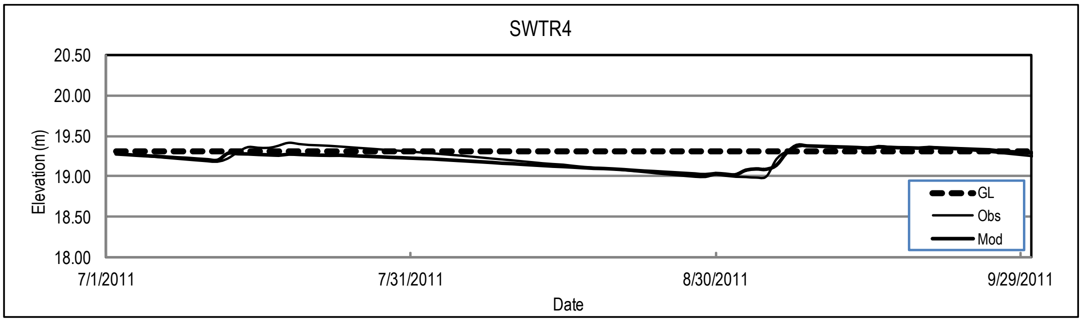
[13] Usup A, Hashimoto Y, Takahashi H, and Hayasaka H. Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia. *Tropics* 2004, **14 (1)**: 1–19.

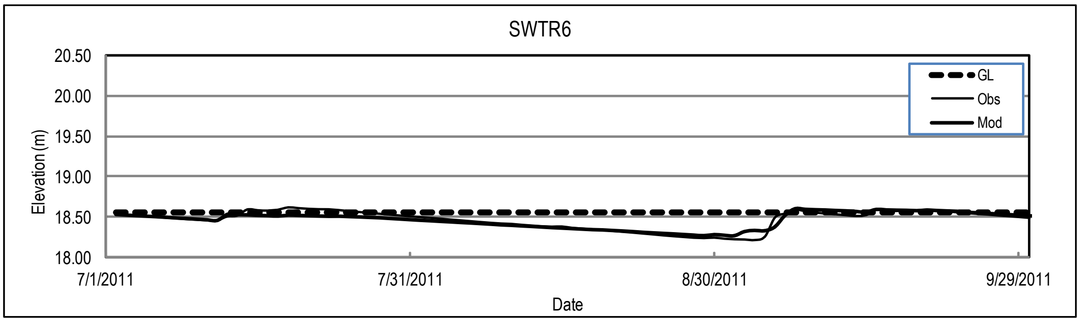
[14] Adiningsih ES. Monitoring El Nino and La Nina phenomenon: the use of remote sensing for land forest fire anticipation. *Warta LAPAN* 2001, **3(2)**: 45-55.

Appendix A. GWL modeling for calibrated year 2011

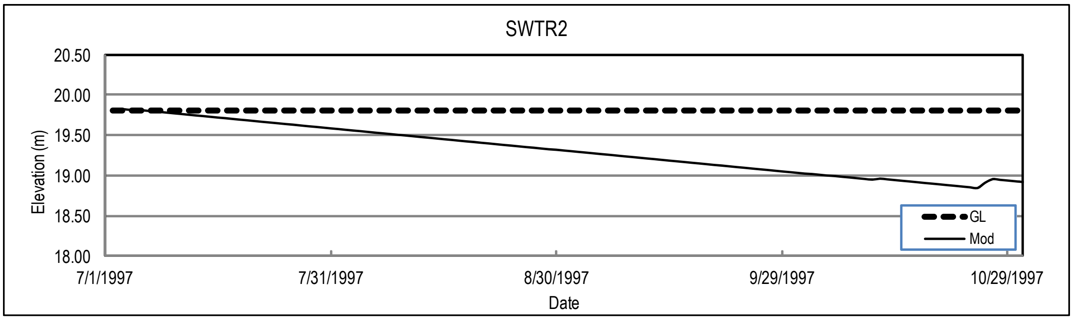


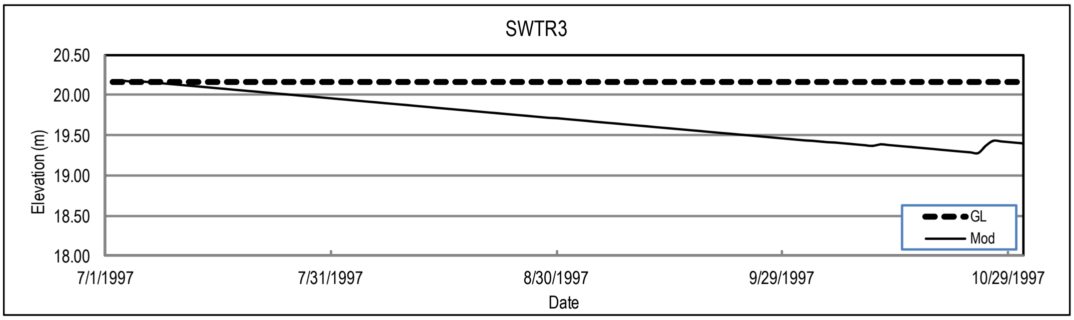


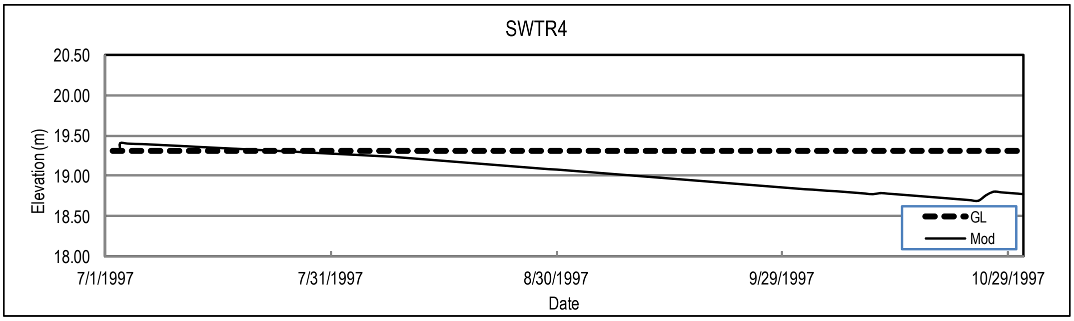


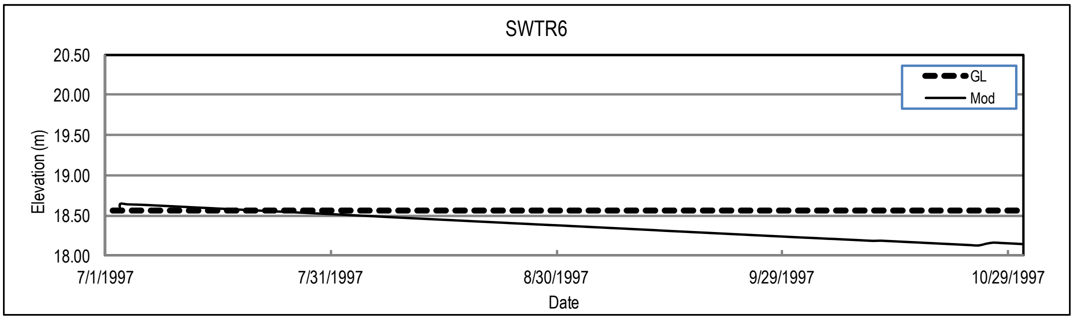


Appendix B. GWL modeling for El Nino year 1997









Appendix C. GWL modeling for El Nino year 2002