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Aquatic Sedimentation Assessment Using Electromagnetic Data in the Scheme of Flood Hazard Mitigation

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Abstract

Sediment thickness increases can cause floodplains and the water level increases. This has the potential to generate a flood. Using electromagnetic waves, Time Domain Electromagnetic (TDEM) detected resistivity or conductivity contrast of lithology in the subsurface. It is measured in the time domain. TDEM method has been developing for decades. Here we tried to develop a 1-D forward modelling program for central loop configuration in the water environment using the Adaptive Born Forward Mapping (ABFM) method. We simulated this program in several water environment conditions (such as freshwater, brackish water and saline water) to know its response. Preventing natural hazards, especially flood hazards which are caused by the floodplain increases is our motivation in this research. Our simulation shows that Central-Loop Configuration Time-Domain Electromagnetic Method is able for imaging the sediment thickness clearly. The response of this method is extremely sensitive in saline water to depth changing than in other water environments.

Key words: sedimentation, natural hazard, flood, floodplain, Electromagnetic, water level

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1. Introduction

Electromagnetic Method is one of the geophysical methods that uses for subsurface conditions imaging based on the conductivity contrast of the medium. Until now, this method is still popularly used in various fields, such as geological hazard mitigation [1,2], caving mitigation [3], water intrusion exploration [4], mineral exploration [5] and environmental investigation [6]. In general, electromagnetic methods are grouped into two, they are the time and frequency domain. The differences is in the electromagnetic frequency domain (FDEM), the data is measured by recording the presence of a signal with a specific frequency. While the Time domain electromagnetic (TDEM) measurement is carried out using a square loop or a circular loop placed on the surface. In this configuration, the transmitter emits a direct short-current pulse and stops at a specific time period.

Surface activities in the aquatic environment, such as weathering are potentially in sedimentary increases and it is leading the water level is rises and cause a flood hazard. The TDEM method is widely used in the aquatic environment. The conductive environment presents a significant challenge in using this method. In this study, we tried to model the TDEM response in different water types to know its sensitivity in water level and sedimentary thickness detection.

2. Data and Method

2.1 Data

The TDEM is a controlled source electromagnetic method which has the principle of injecting currents into the subsurface and turning them off for a certain period of time [1,7,8]. The resulting response will depend on the physical properties, here is conductivity and the thickness of the medium. In this study, we used synthetic data generated from the conceptual model to determine the 1-D response of TDEM which is shown in Figure 1.

The conceptual model consists of geological and geophysical profiles on a sub-sectional system of water-containing environments (freshwater, brackish water and saline water). Synthetic lithology, in the next, is called sedimentary layers, and its thickness is the geological synthetic component while the conductivity contrast is the physical property that images with the geophysical method such as TDEM. The model has five layers: water, soil,

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clay, medium sand gravel and sandstone as bedrock. Here we simulate different water conditions while the same geological feature for each model and divide it into four interest points, called S-1, S-2, S-3 and S-4. Thus, the response in different water thicknesses can be gotten. Table 1 shows the geological and geophysical parameters that we used in this study.

Tabel 1. The conceptual model parameters

Lithology	Resistivity (ohm.m)
Sandstone	700
Soil	25
Clay	50
Medium Sand Gravel	140
Freshwater	10
Brackish water	4.5
Saline water	0.3

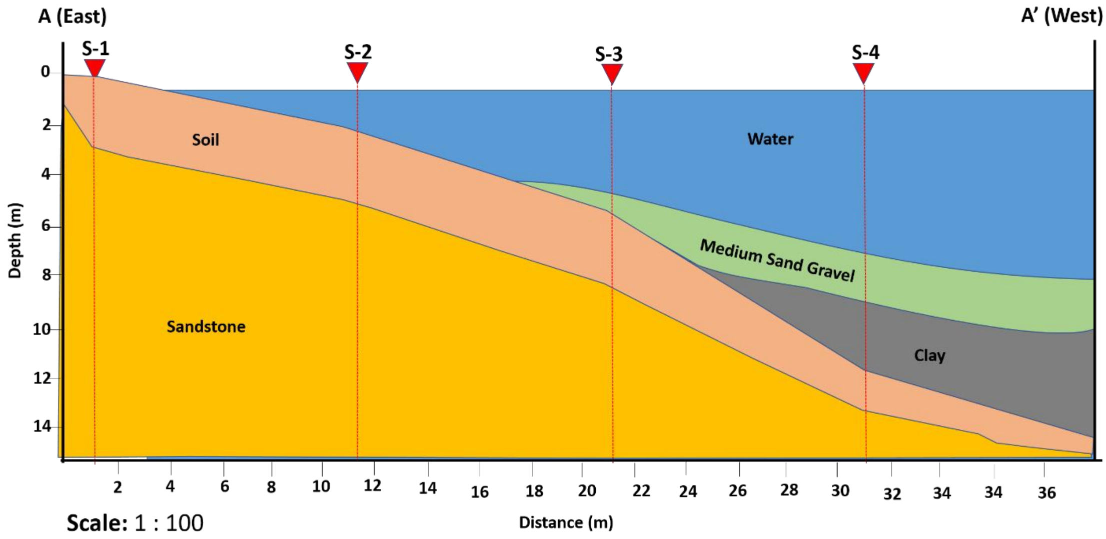


Figure 1. Geological conceptual model

2.2 Method

In TDEM using a central loop configuration, the secondary field magmatic will be generated because of the magnetic field variation over time. During the acquisition of this method, the secondary field magnetic and its derivative will be conducted. Assuming the medium is homogenous half-space, the secondary field magnetic can be estimated using the equation:

$$\frac{\partial H_z}{\partial \mathrm{t}} = -\frac{I}{\mu_0 \sigma a^3}\left[3\,\mathrm{erf}\,(\theta a) - \frac{2}{\sqrt{\pi}}(3 + 2\theta^2 a^2)e^{-\theta^2 a^2}\right] \quad \text{... (1)}$$

θ and error function determined by this equation below:

$$\theta = \sqrt{\frac{\mu_0 \sigma}{4t}} \quad \text{... (2)}$$

$$\mathrm{erf}\,(\theta a) = \frac{1}{\sqrt{\pi}}\int_{-\theta a}^{\theta a} e^{-t^2} dt \quad \text{... (3)}$$

The secondary derived magnetic field can be transformed into apparent resistivity using the following equation:

$$\rho_a \approx \frac{I^{0.667}(\mu_0)^{1.667} a^{1.333}}{20^{0.667}\pi^{0.333}t^{1.667}}\left(\frac{-\partial H_z}{\partial t}\right)^{0.6667} \quad \text{... (4)}$$

The TDEM response at each observation point is obtained by doing forward modelling. We use Adaptive Born Forward Mapping (ABFM) method to calculate the forward modelling response. This method describes the response changes as a function of the subsurface conductivity contrast. The forward modelling process was carried out by floating process, and the apparent conductivities are unknown before the response from forward modelling is calculated. So, the initiation model is needed. The apparent conductivity is calculated as a function of time denoted by the index j $\sigma_a(t_j)$ for each layer using the Equation (1). Deconvolution or other non-unique transformations are not required in this method [7,8].

$$\sigma_a(t_j) = \sum_{k=1}^{L} \sigma_k F_{jk} \quad \text{... (5)}$$

σ_k is the conductivity model for each layer k. The Fréchet kernel equation (F_{jk}) which is change with depth (z) is used to obtain the apparent conductivity of the conductivity model. The Fréchet kernel function is calculated using the equation below:

$$F\left(z_k, t_j, \sigma_a(t_j)\right) = f(x) = \begin{cases} \frac{z_k}{D_j}\left(2 - \frac{z_k}{D_j}\right), & for\ z_k \le D_j \\ 1, & for\ z_k > D_j \end{cases} \quad \text{... (6)}$$

With variable D_j is

$$D_j = \sqrt{\frac{ct_j}{\mu_0 \sigma_a(t_j)}} \quad \text{... (7)}$$

The ad hoc scaling is symbolized by c and free space magnetic permeability is symbolized by μ_0 which are 1.2 and $4\pi \times 10^{-7}$. In our modelling, we use α of 0.4, current I of 10 A. [6] suggest that the goodness forward modelling result will be gotten at least after 5-10 times of iteration. In this study, we applied 20 times iterations to get the most optimum result. In this process, the initial value of the conductivity model σ_a^k is needed. We set the average of the conductivity model as an initial σ_a^k value, then the iteration process was done following the equation below:

$$\sigma_a^k = \alpha\sigma_a^{k+1} + (1+\alpha)\sigma_a^k \quad \text{... (8)}$$

3. *Results*

4.1 TDEM Response in the Different Water Types

In this study, we obtained four models for each water type, they are shown in Figure 2 till Figure 4. The response of the TDEM is described by red dots and the depth of the sedimentary layer model is shown by the blue line. S-1 point consists of soil and sandstone, where the conductivity contrast is significant between these. We set the soil depth as 3 metres. The lithology of S-2 is water (2 meters), soil (3 metres) and sandstone. While S-3: water (5 metres), medium sand gravel (1 metre), soil (3 metres) and sandstone. S-4 point consists of water (7 metres), medium sand gravel (2 metres), clay (4 metres), soil (1.5 metres) and sandstone. Our result shows that the little depth changes do not significantly change the TDEM response. Therefore from model S-2 (2metre water depth) to S-4 (7metre water depth), all model responses show significant changes. The comparison between S-2, S-3 and S-4 responses show that the sedimentary thickness change can be detected by this method.

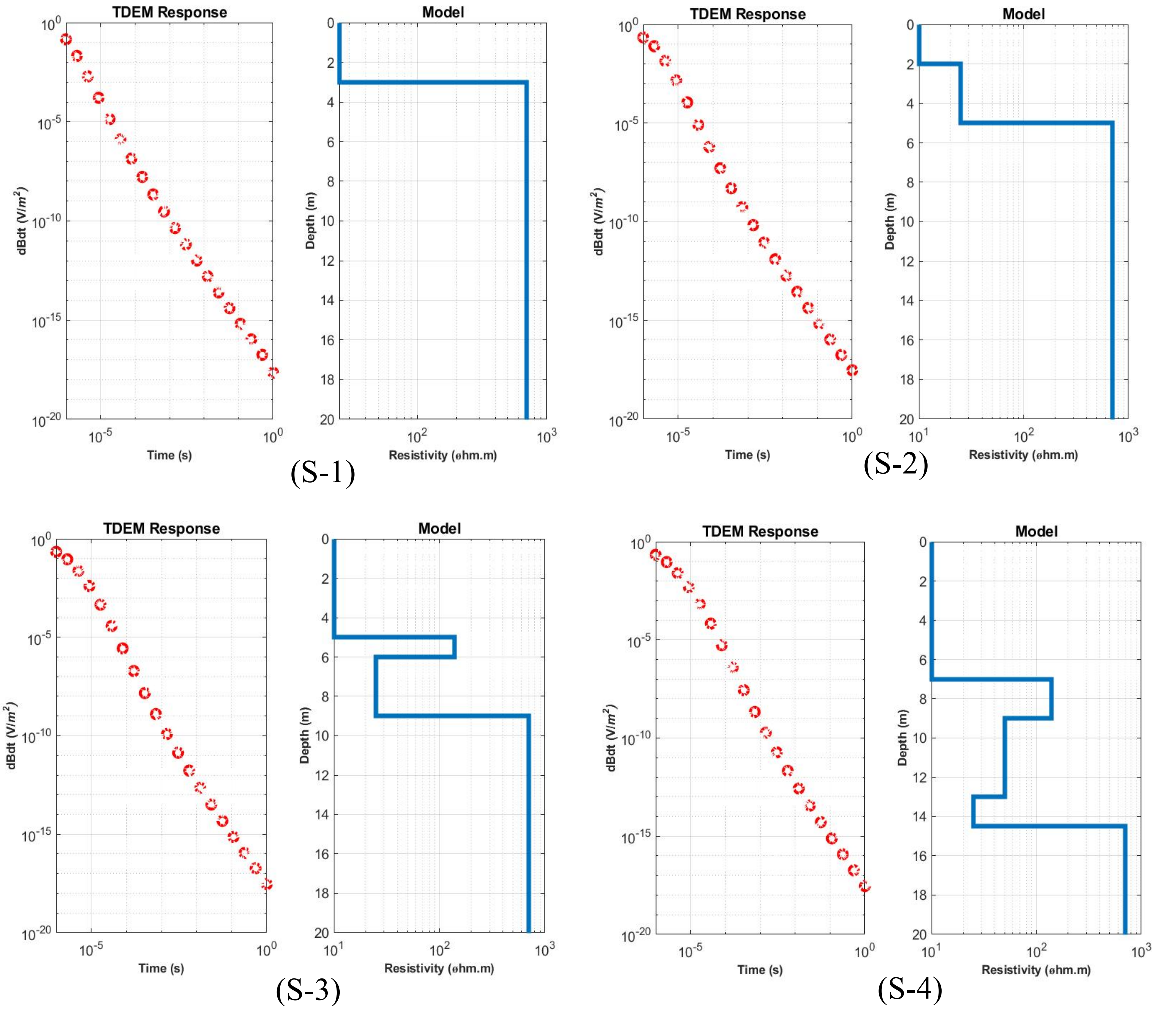


Figure 2. TDEM response in freshwater

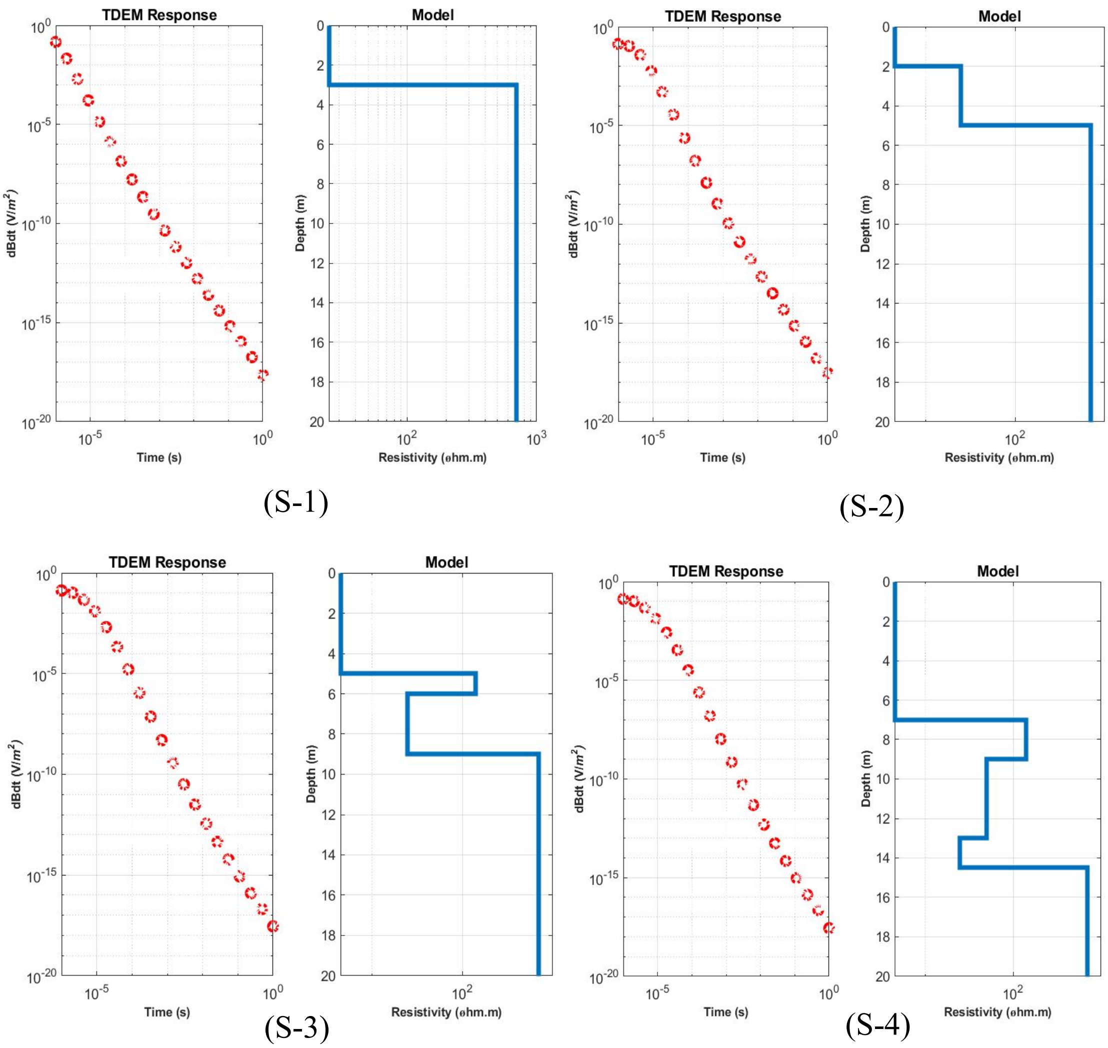
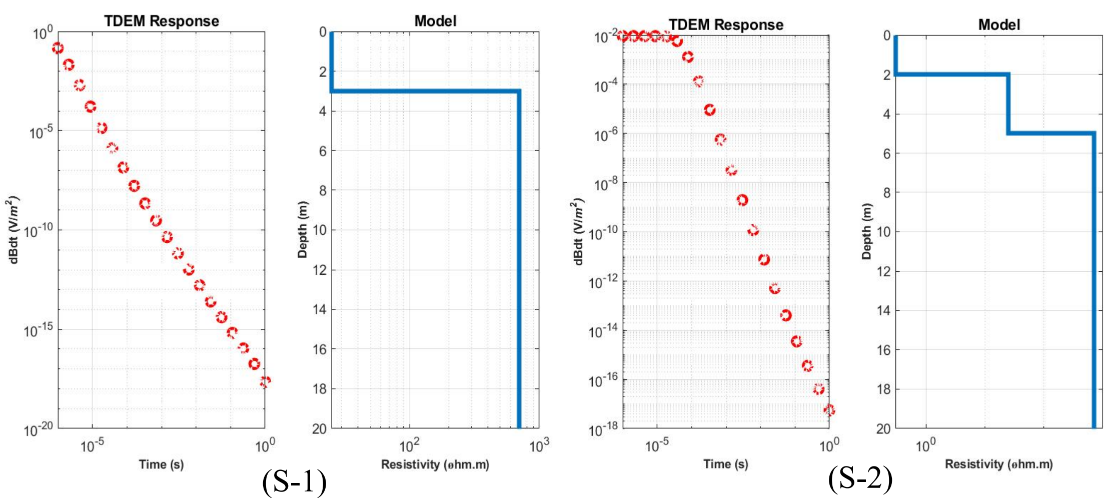
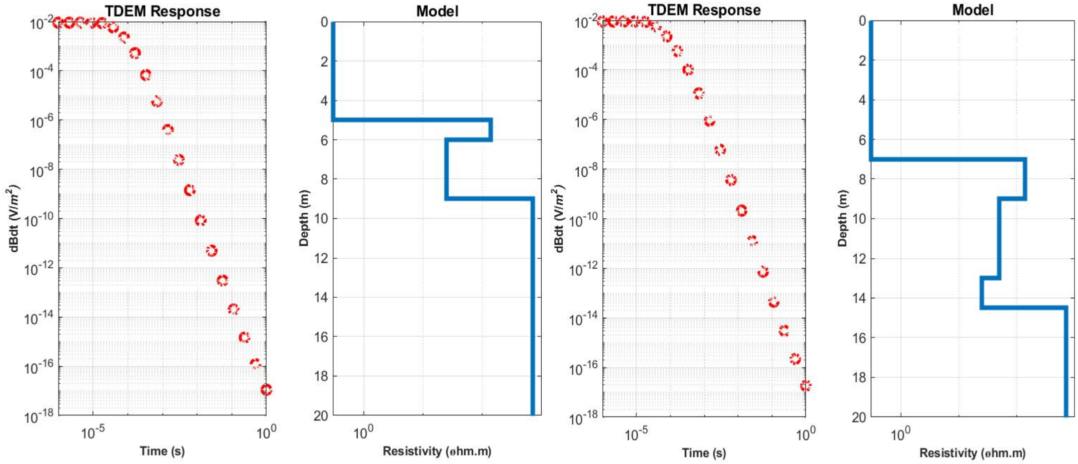


Figure 3. TDEM response in brackish water



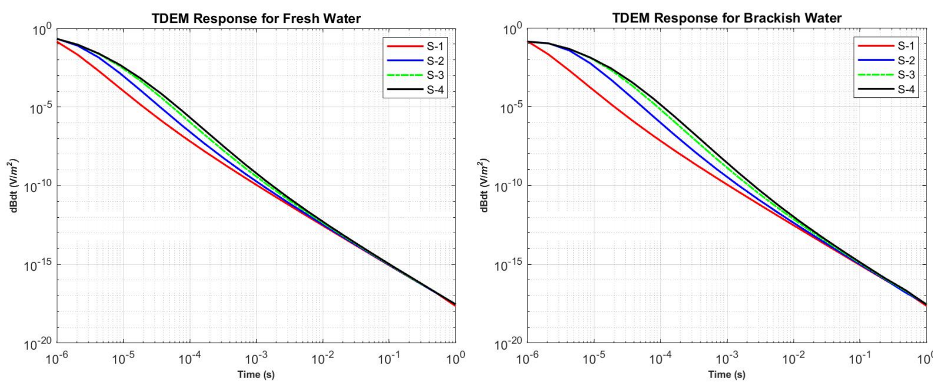


(S-3) (S-4)

Figure 4. TDEM response in saline water

4.2 Comparison TDEM Response in the Different Sedimentary Thickness

Here we show how TDEM responses to the thickness rise of the sedimentary layer. In the same water type and with different sediment thicknesses, the response is shown in Figure 5. The red, blue and black lines sign the response at each point. The water and lithology thickness increase from S-1 to the S-4 point. We found that the results match theoretically, where the thicker sedimentary layer has a higher response. In the brackish and saline water, the response is significantly sensitive based on the comparison between the response at S-2 and S-4 points. In the sedimentation assessment, this information is needed for the approximation of sedimentary thickness. Sedimentary rises potential to increase the water level and lead the flood hazard.



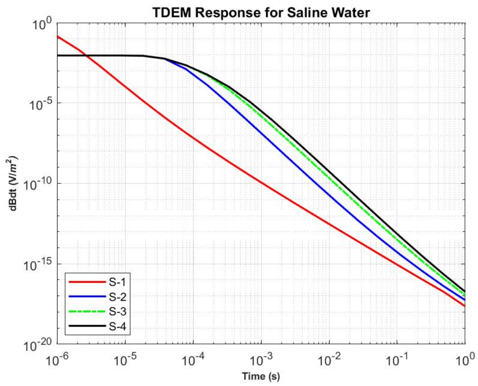


Figure 5. Comparison TDEM response for each model

4. Discussion

5.1 TEDM Sensitivities Comparison

Figure 6 shows the TDEM response changes in the different water types with the same thickness. At the S-2 point, freshwater and brackish water almost have the same response in the shallow depth, and it changed in the deeper depth. In the greater deeper, we found that the freshwater and brackish water have the same response. It means that the TDEM is sensitively enough to detect different water types. Here we also show how the upper layer influences the lower layer. It is because the response is a function of time. Freshwater and brackish water in deeper depths have almost overlapping, but not for saline water.

If sedimentary is not significantly changed, it is not easy to conclude that it has changed by perceiving the TDEM response only. It is also shown by the water response at S-3 and S-4 which is the thickness only changes 2 metres thicker. So, to know the changes, the inversion proses from TDEM response to depth information is needed.

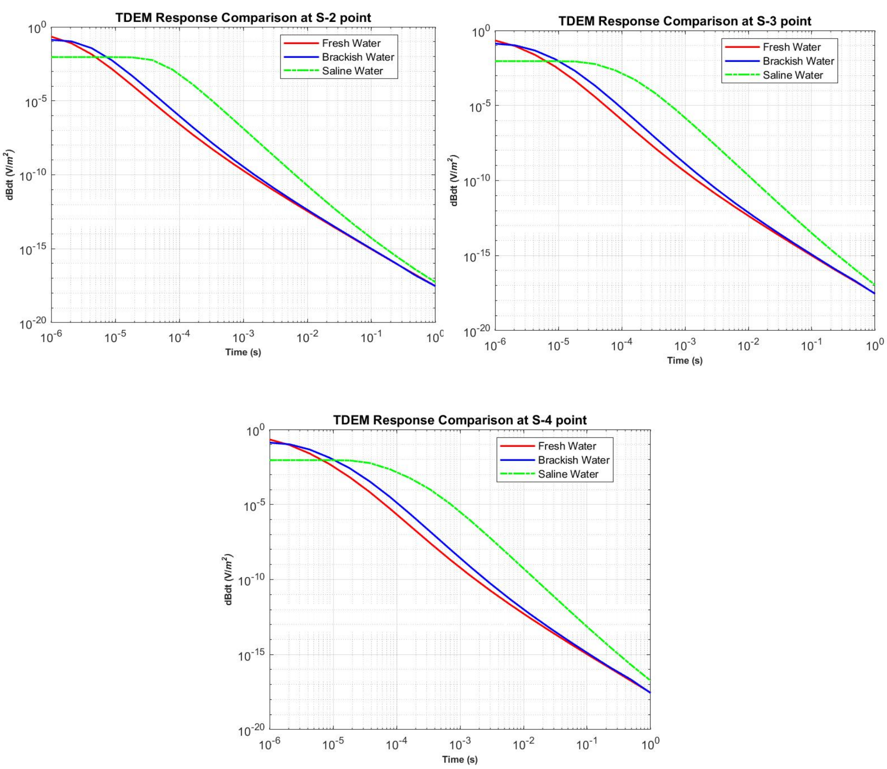


Figure 6. Comparison TDEM response for each model

5.2 Synthetic Apparent Resistivity Curves

In this section we show the apparent resistivity changes for all the water types. The resistivity curve for freshwater, brackish water and saline water are shown in Figure 7, 8 and 9. Responses at each interest point are signed by lines blue, red, green and black on each curve. The apparent resistivity curve will tend downward in the thicker water because the medium relatively conductive than other medium around it. The significant changes is happen in saline water if it compare with the S-1 response.

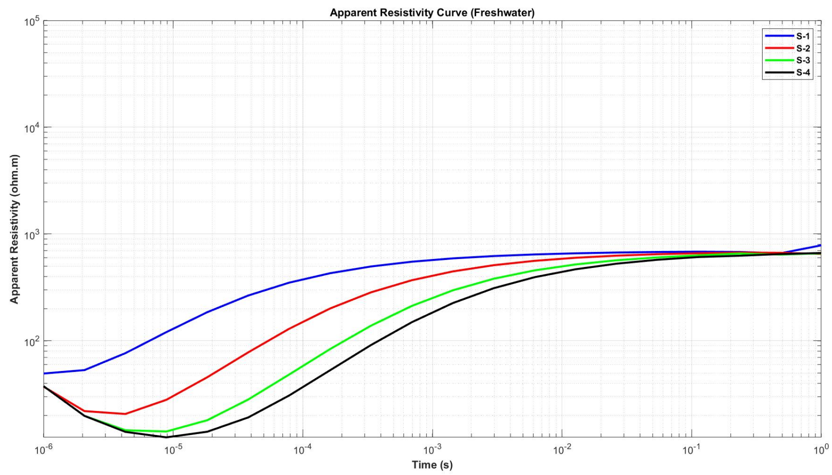


Figure 7. The apparent resistivity curve of freshwater

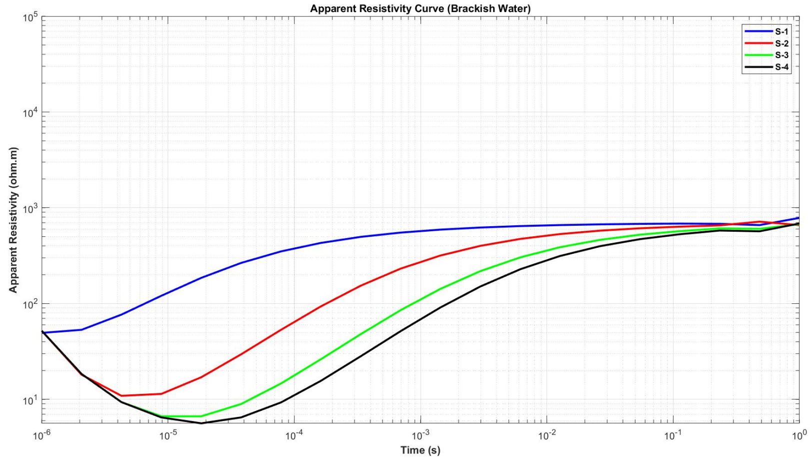


Figure 8. The apparent resistivity curve of brackish water

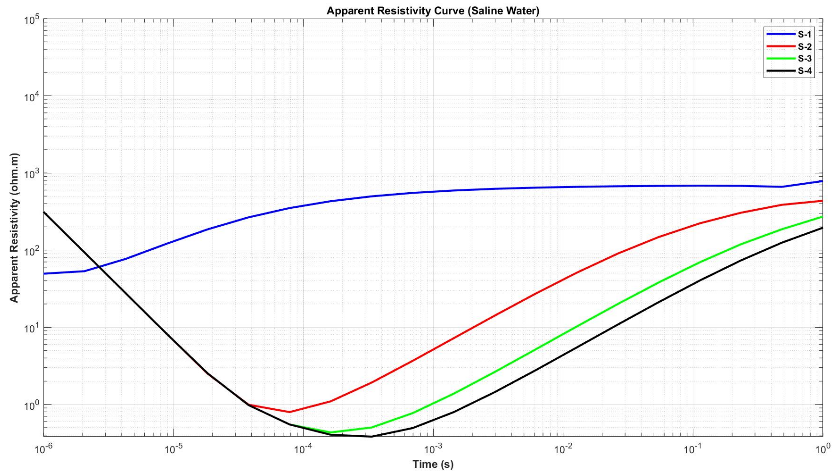


Figure 9. The apparent resistivity curve of saline water

5. Conclusion

The sedimentary assessment in flood hazard schema is to know the depth changes of it. Based on our forward modelling, we conclude that the TDEM method is able to use in freshwater, brackish and saline water. The water and sedimentary layer can be detected by this method. If we compare the result to each other, this method is relatively sensitive to depth changes of saline water and also sensitive to the layer which is significantly changed in depth from the upper layer. In the water level changes cases study because the sedimentary layer increases, this method can be applied.

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