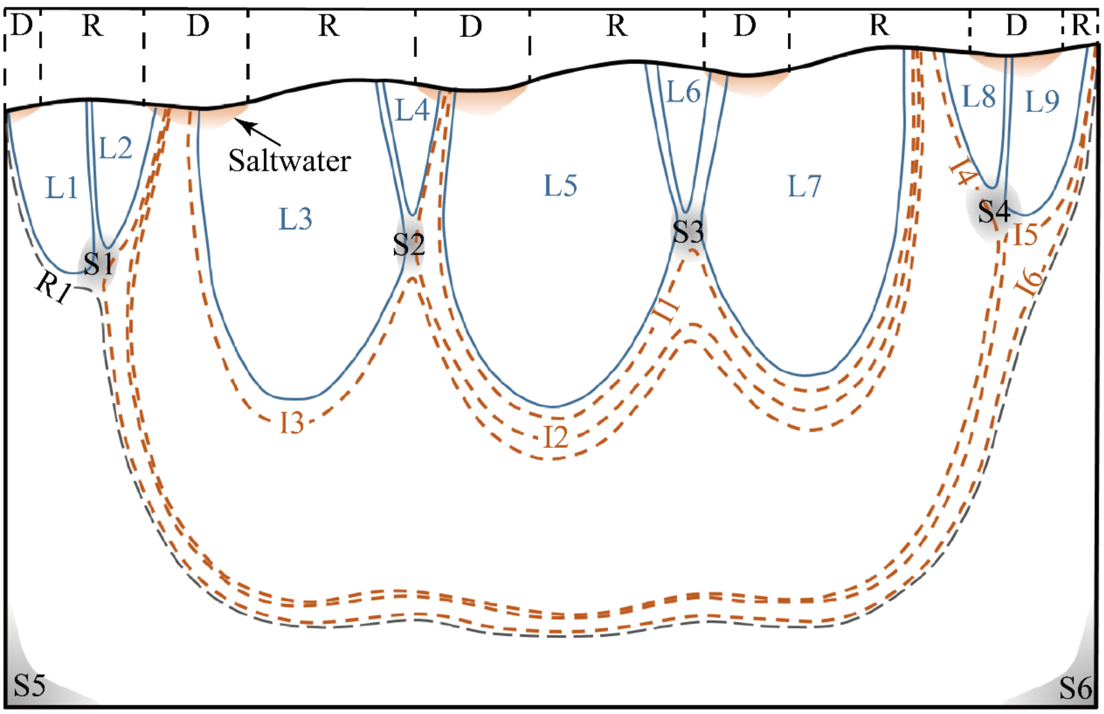

Fig. 1. Theoretical model with saltwater infiltration. S1 to S6 denote the stagnation points. In this study, total 16 streamlines close to stagnation points S1-S4, including 9 local streamlines, 6 intermediate streamlines, and 1 regional streamline, are enough to divide the flow systems. Owing to the periodic undulations of the water table, there are nine local flow systems (from L1 through L9). Intermediate flow system IF1, IF2, and IF3 are divided by streamlines I1 and I2, I3 and I4, I5 and I6, respectively. The domain below streamline R1 is occupied by regional flow. The orange areas near the water table show the high salinity zone due to saltwater infiltration. D and R denote discharge and recharge zones, respectively.

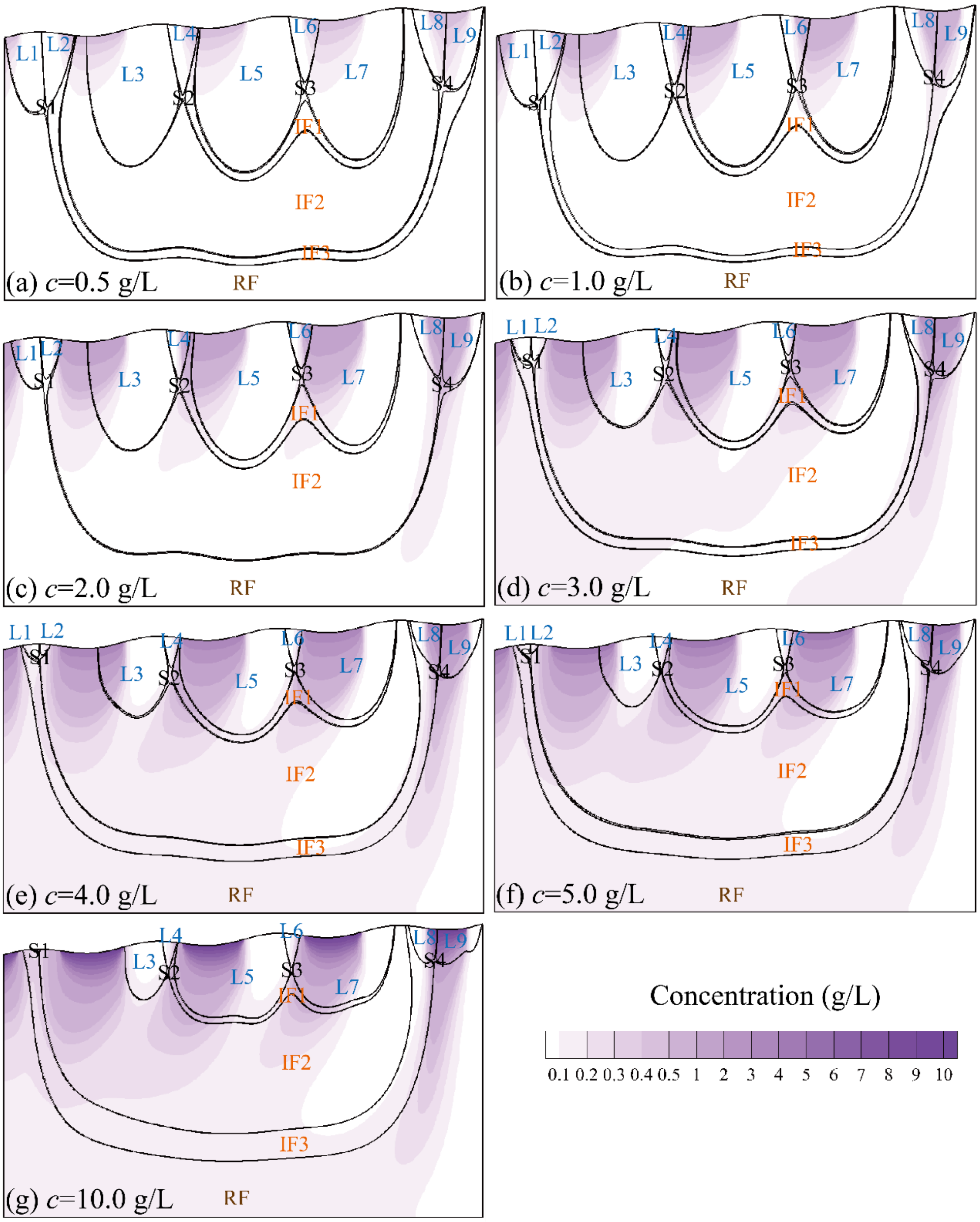

Fig. 2 Distributions of saltwater concentrations resulting from different boundary saltwater concentrations *c* in the discharge zones. L, IF, and RF denote the local, intermediate, and regional groundwater flow system, respectively.

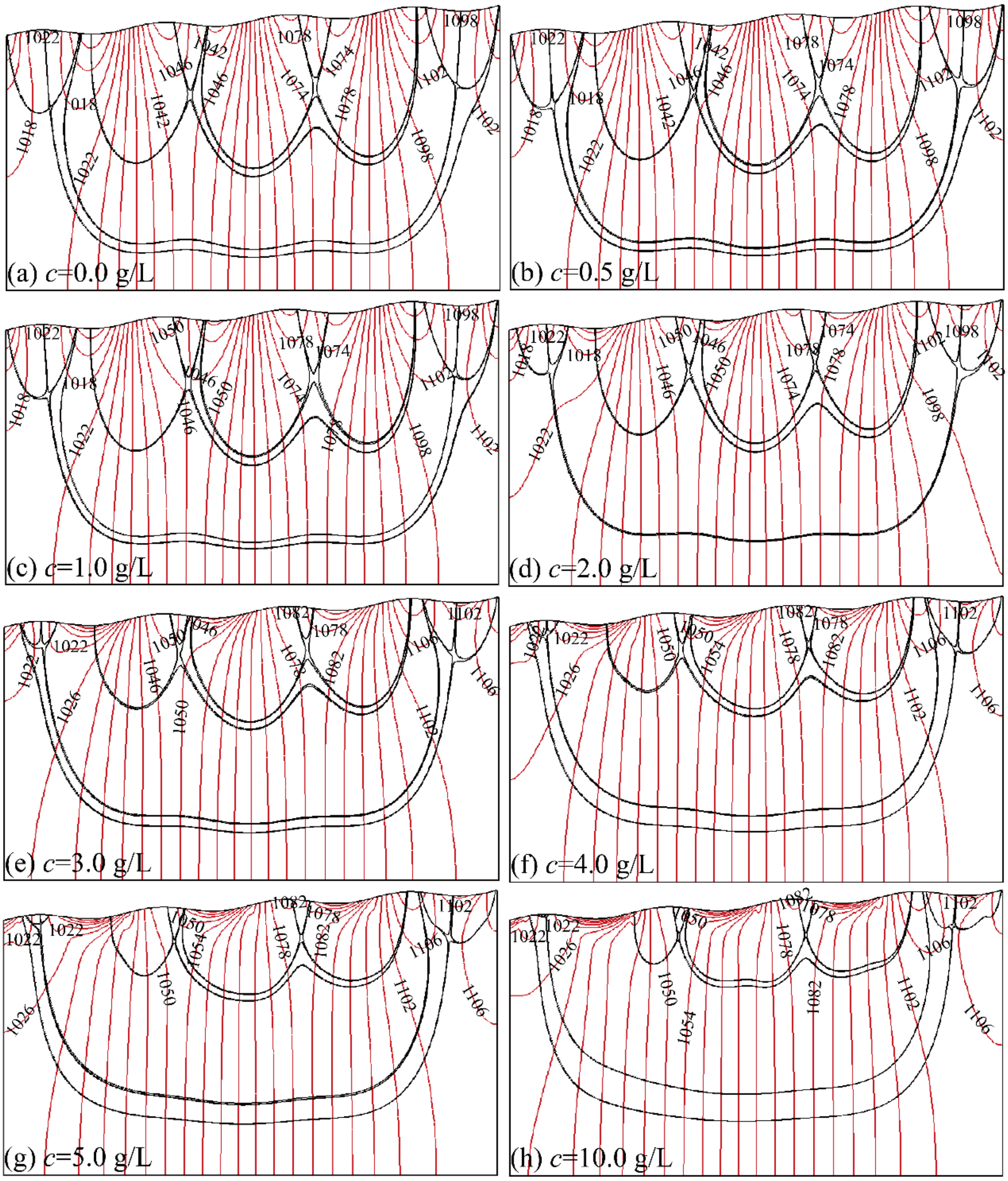

Fig. 3 Distributions of hydraulic head (red) (m) at 4 m increment and streamlines (black) resulting from different boundary saltwater concentrations *c* in the discharge zones.

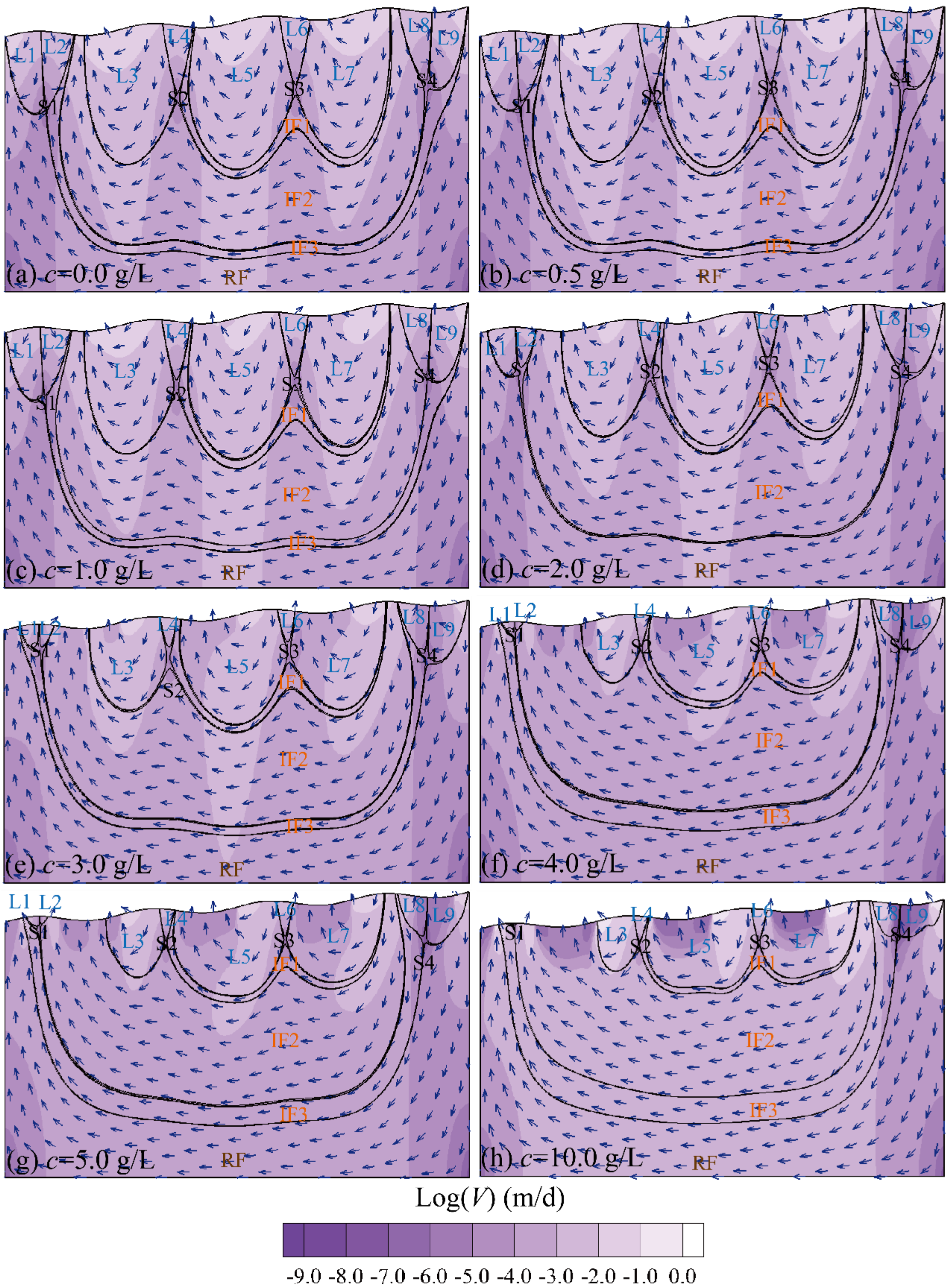

Fig. 4 Darcy velocity magnitude V (m/s) contours, streamlines (black) and velocity field (blue) resulting from different boundary saltwater concentrations c in the discharge zones. L, IF, and RF denote the local, intermediate, and regional groundwater flow system, respectively.

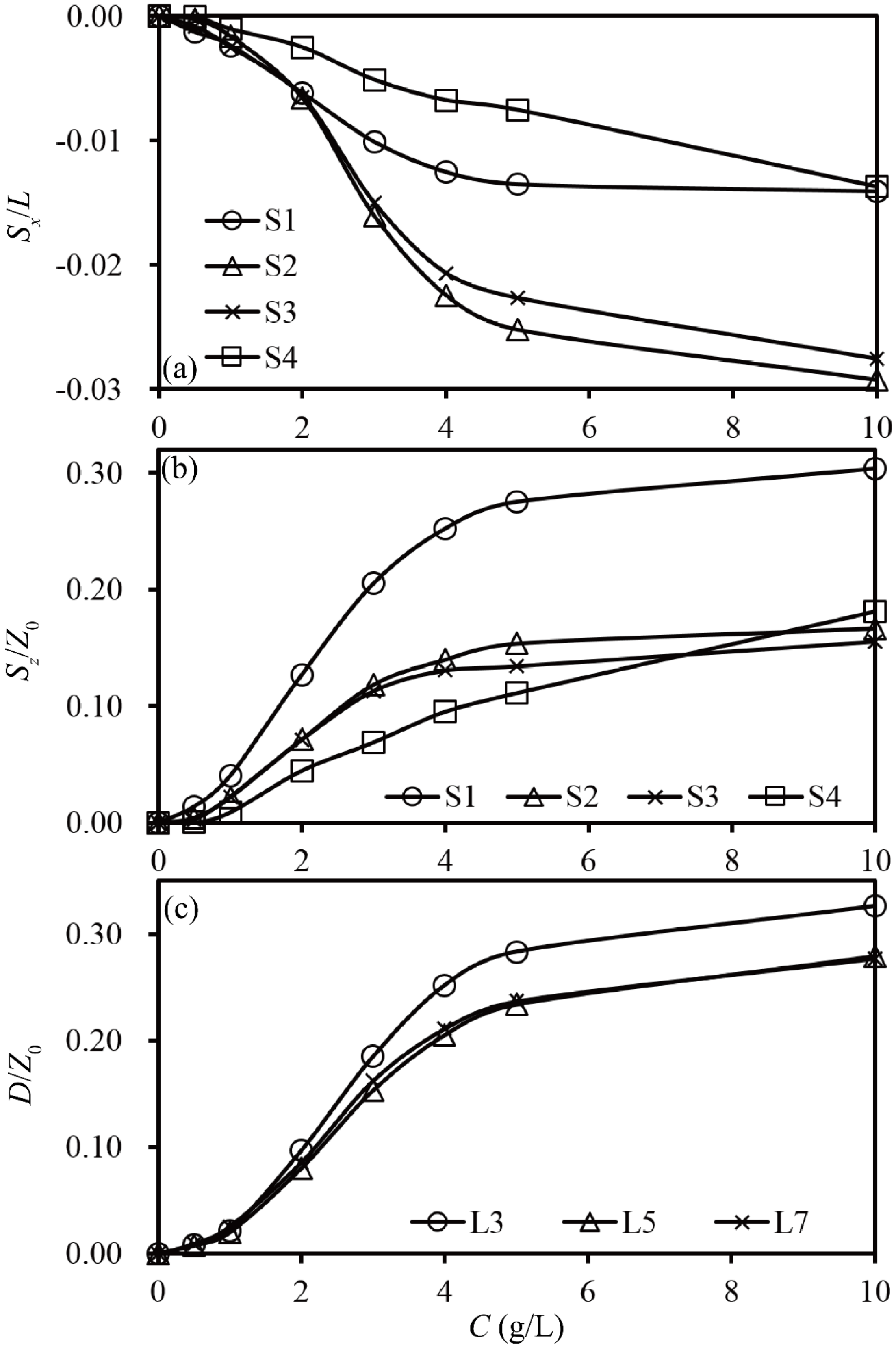

Fig. 5. Displacements of stagnation points and local flow penetration depth.

The variations of dimensionless displacements of four stagnation points in the x-direction (a) and in the z-direction (b) with saltwater concentrations , respectively (L=6000 m and Z_0=1000 m). (c) The variations of dimensionless displacements of penetration depth of three local flow systems with saltwater concentrations. The locations of S1, S2, S3, and S4 and L3, L5, and L7 are shown in Fig. 1.

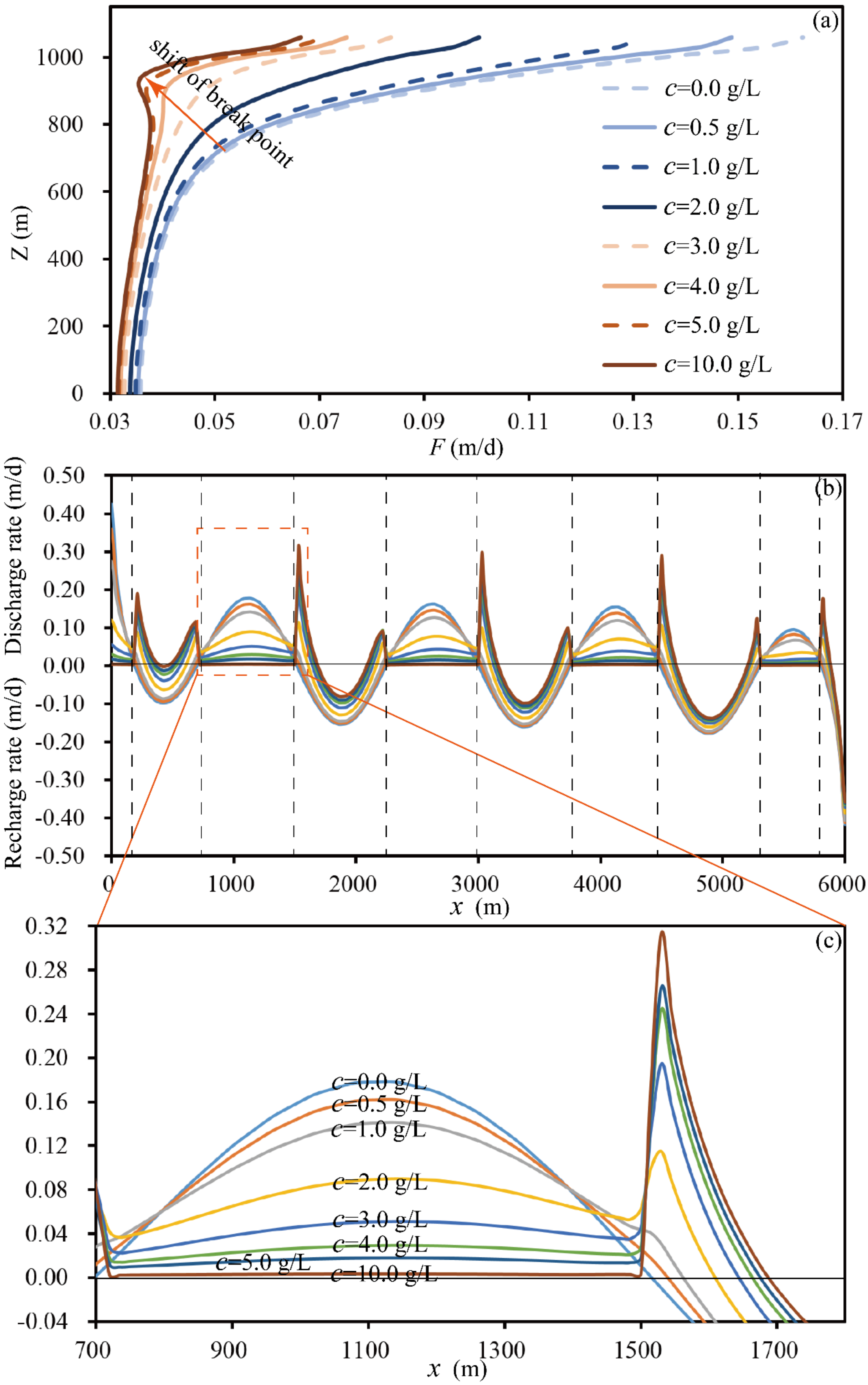

Fig. 6. (a) Flushing intensity (F) profiles for different saltwater

concentrations in the discharge zones. (b) and (c) recharge and discharge rate distribution (m/d) at the upper boundary of the domain.

Table 1. HydroGeosphere Model Parameter Values and Attributes

Description	Value	Unit	Reference
Hydraulic conductivity	1	m/d	Jiang et al., [2009]
Longitudinal dispersivity	10	m	giving the local scaled dispersivity 10÷(6000÷9)=0.015, referred from Fan et al. [1997]
Lateral dispersivity	1	m	giving lateral dispersivity/longitudinal dispersivity=0.1
Molecular diffusion coefficient	8.64×10^{-6}	m^2/d	
porosity	0.375	—	typical value for silt
Fresh water density	998.402	kg/m^3	
Fresh water viscosity	86.54	Pa·d	fresh water dynamic viscosity at 20℃
Maximum saltwater concentration	10	g/L	
Maximum saltwater viscosity	133.966	Pa·d	from Eq. (5)
Maximum saltwater density	1005.81	kg/m^3	from *El-Dessouky and Ettouney*, [2002]

Table 2. S_x/L (dimensionless displacements of stagnation points in the x-direction), S_z/Z_0, (dimensionless displacements of stagnation points in the z-direction), and D/Z_0 (dimensionless displacements of penetration depth of local flow systems) for different concentration, regression equations, and intercepts of the equations at c-axis (The locations of S1, S2, S3, and S4 and L3, L5, and L7 are shown in Fig. 1; L=6000 m and Z_0=1000 m)

		Saltwater concentration (g/L) in the discharge zones							Regression equation	Intercept at c-axis
		0.5	1	2	3	4	5	10		
S_x/L	S1	-0.0013	-0.0024	-0.0062	-0.0101	-0.0125	-0.0135	-0.0141	y = -0.004ln(c) - 0.0012 R^2 = 0.89	1.35
	S2	-0.0002	-0.0016	-0.0066	-0.0161	-0.0224	-0.0252	-0.0292	y = -0.005ln(c) - 0.004 R^2 = 0.93	2.23
	S3	-0.0008	-0.0025	-0.0065	-0.0150	-0.0207	-0.0226	-0.0275	y = -0.01ln(c) - 0.0045 R^2 = 0.93	1.51
	S4	0.0000	-0.0010	-0.0025	-0.0051	-0.0067	-0.0075	-0.0137	y = -0.011ln(c) - 0.0043 R^2 = 0.92	1.48
		0.5	1	2	3	4	5	10		
S_z/Z_0	S1	0.0140	0.0402	0.1269	0.2052	0.2523	0.2753	0.3038	y = 0.1113ln(c) + 0.0722 R^2 = 0.95	1.91
	S2	0.0043	0.0217	0.0714	0.1184	0.1398	0.1539	0.1667	y = 0.0626ln(c) + 0.0394 R^2 = 0.95	1.88
	S3	0.0028	0.0221	0.0711	0.1129	0.1307	0.1342	0.1555	y = 0.0573ln(c) + 0.0375 R^2 = 0.96	1.92
	S4	0.0002	0.0089	0.0446	0.0688	0.0952	0.1111	0.1670	y = 0.0568ln(c) + 0.0189 R^2 = 0.94	1.39
		0.5	1	2	3	4	5	10		
D/Z_0	L3	0.0081	0.0216	0.0970	0.1851	0.2520	0.2832	0.3260	y = 0.122ln(c) + 0.0561 R^2 = 0.94	1.58
	L5	0.0077	0.0199	0.0803	0.1533	0.2052	0.2338	0.2791	y = 0.1022ln(c) + 0.0465 R^2 = 0.94	1.58
	L7	0.0092	0.0255	0.0859	0.1623	0.2112	0.2368	0.2771	y = 0.1014ln(c) + 0.0513 R^2 = 0.95	1.66

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