WS-4 ：同位体分析結果考察

Characteristics of the Groundwater in the Rift Valley Lakes Basin

- Isotopic Analysis Results -

**Technical Transfer Seminar
for the Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin**

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

Contents of this Presentation

1. Clarify the nature of the groundwater in the area 10 min

2. Results and interpretation of isotope analysis 20 min

3. Case of utilization of the isotope analysis in Japan 15 min

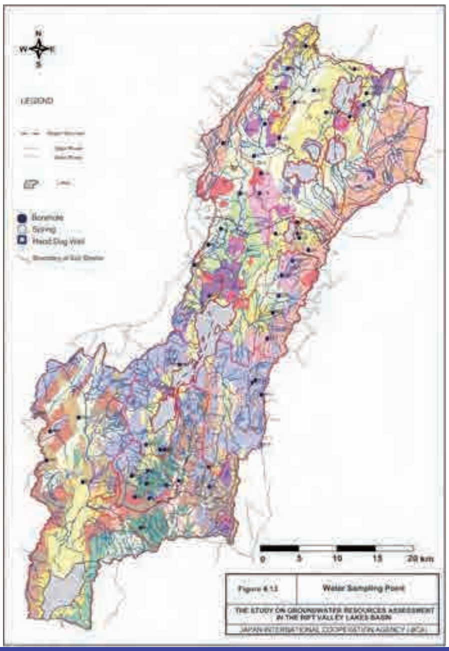
The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 :同位体分析結果考察

1 Nature of groundwater by water quality analysis

1.1 Sampling point

Bno	BasinName	Samp_P_ID	Geology	SourceType	Eastings	Northings	Remarks
1	Western Ziway-Abjata	WZA1	Qwbh	spring	440353.00	918436.00	
		WZA2	N1_2n	Borehole	449814.00	918599.00	
		WZA3	Qwbh	Borehole	436107.39	901949.82	
		WZA4	Qdi	Borehole	426750.58	887592.79	
		WZA5	Qdi	Borehole	455903.00	885591.00	
		WZA6	Qdi	Borehole	440921.00	876752.00	
		WZA7	Ql	Borehole	465363.00	869206.00	
2	Eastern Ziway	EZ1	Ql	Borehole	487538.00	901548.00	
		EZ2	Ql	spring	495889.00	895142.00	
		EZ3	Ql	spring	502396.00	887587.00	
		EZ4	Ql	Borehole	496746.00	883403.00	
		EZ5	Qwbh	Borehole	494507.00	874562.00	
		EZ6	Ql	spring	485555.00	872111.00	
		EZ7	Ql	Borehole	483552.00	866076.00	
3	Lake Shalla	LS1	Qdi	spring	410040.00	872237.00	
		LS2	Qwpu	spring	414532.00	863503.00	
		LS3	Qdi	Borehole	418241.00	860616.00	
		LS4	Qwpu	spring	403414.00	855821.00	
		LS5	N1_2n	Borehole	429417.53	850002.26	
		LS6	Qwbh	spring	420168.00	844740.00	
4	Lake Langono	LL10	Qdp	Borehole	413811.47	808766.15	
		LL11	Qdi	spring	471440.00	799751.00	
		LL12	Qdi	spring	481628.00	820252.00	
		LL7	Qdi	Borehole	409686.00	836778.00	
		LL8	Qdi	spring	413167.00	831630.00	
		LL9	Qws	Borehole	414848.79	823508.22	
5	Lake Awasa	LA1	Qws	Borehole	443247.00	787145.00	
		LA2	Qdi	spring	458768.00	783746.00	
		LA3	Ql	Borehole	426416.00	778488.00	
		LA4	Ql	Borehole	443296.00	778694.00	
		LA5	Qws	Borehole	444891.00	775368.00	
		LA6	N1_2n	spring	459970.00	773976.00	
		LA7	NQs	Borehole	451604.00	766446.00	
6	Bilate	B1	NQs	spring	412472.00	893811.00	
		B2	NQs	Borehole	395635.00	846152.00	
		B3	Qdi	Borehole	399050.00	806866.00	
		B4	Qdi	Borehole	363940.00	782098.00	
		B5	Qdi	Borehole	374310.00	770468.00	
		B6	Qws	spring	403650.00	766500.00	
7	Amessa Guracha	AG1	NQs	Borehole	363549.00	755433.00	
		AG2	Qwbp	spring	379661.00	743494.00	
		AG3	Qwbp	Borehole	374898.00	732412.00	
		AG4	[illegible]	spring	354515.00	723336.00	
		AG5	Pv	spring	352367.00	718157.00	
		AG6	Pv	spring	347611.00	713476.00	
8	Gidabo	GID1	Qdp	Borehole	439758.00	758663.00	
		GID2	Qdp	spring	438017.00	753002.00	
		GID3	Qdp	Borehole	431299.00	747854.00	
		GID4	Qdi	hand dug well	428801.00	732211.00	
		GID5	Qa	Borehole	424600.00	720000.00	
		GID6	PNv	spring	427915.00	706700.00	
		GID7	PNv	Borehole	420150.00	701089.00	
9	Kulfo Gina	KG1	Pv	spring	345897.00	704036.00	
		KG2	Pv	spring	342307.00	691646.00	
		KG3	PNv	spring	342008.00	684900.00	
		KG4	Pv	spring	343470.00	682077.00	
		KG5	Qa	Borehole	351823.00	681377.00	
		KG6	Pv	spring	335938.00	664942.00	
		KG7	Qwbp	spring	340514.00	663331.00	
10	Sife Chamo	SC1	Pv	spring	313955.00	652539.00	
		SC2	Qa	spring	325813.00	650053.00	
		SC3	Pv	spring	323955.00	631606.00	
		SC4	Qa	Borehole	326268.00	621806.00	
		SC5	NMt	Borehole	337177.93	618029.40	
		SC6	NMt	Borehole	340044.00	618188.00	
11	Gelana	GEL1	Pv	spring	413097.00	680370.00	
		GEL2	PNv	Borehole	410584.00	669815.00	
		GEL3	PNv	Borehole	408331.00	668006.00	
		GEL4	PNv	Borehole	415473.00	659170.00	
		GEL5	Pcgn4	spring	408449.00	633710.00	
		GEL6	Pv	spring	413840.00	621971.00	
12	Bezo Weyto	BW1	Pcgn4	spring	299599.00	669160.00	
		BW2	Pv	spring	308307.00	666051.00	
		BW3	Pcgn4	Borehole	273518.78	641784.04	
		BW4	Pcgn3	spring	241142.00	645216.00	
		BW5	NQs	Borehole	251506.68	631850.39	
		BW6	Pcgn4	Borehole	248647.00	610123.00	
		BW7	QHr	Borehole	276954.74	593722.42	
13	Konso Localized	KL1	Qa	Borehole	327166.32	602575.18	
		KL2	Pcgn1	Borehole	314963.82	598184.77	
		KL3	NMt	Borehole	326032.44	592626.67	
		KL4	Pcgt4	Borehole	317138.94	582698.21	
		KL5	Pcgn1	Borehole	328439.00	581952.00	
		KL6	NMt	Borehole	341546.24	591483.08	
14	Segen	S1	NMt	spring	366914.00	649685.00	
		S2	Qe	Borehole	351527.97	594777.38	
		S3	Qe	Borehole	374494.00	605132.00	
		S4	Pv	Borehole	374737.00	590400.00	
		S5	Pcgn4	spring	378773.00	581400.00	
		S6	NMt	Borehole	321726.00	559650.00	



The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

1 Nature of groundwater by water quality analysis

1.2.1 Trilinear Diagram (reference)

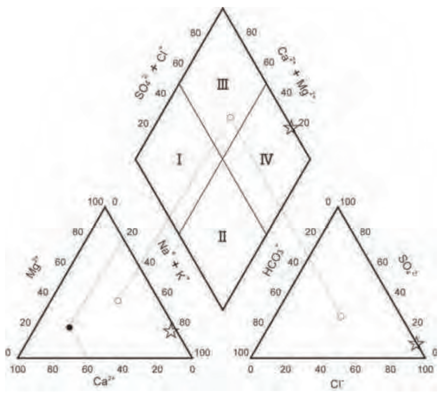


Figure 4.9 :Trilinear Diagram

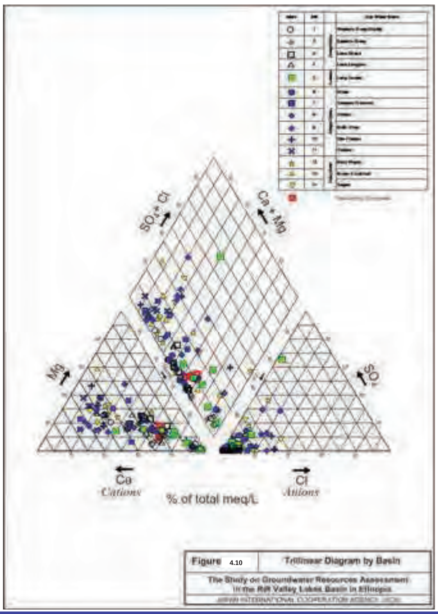
I Ca(HCO3)2 Type (Carbonate hardness): Shallow groundwater, River water
II NaHCO3 Type (Carbonate alkali): Deep groundwater
III CaSO4 CaCl2 Type (Noncarbonate hardness):
IV NaSO4 NaCl (Noncarbonate alkali):Seawater, fossil saline water, hot spring

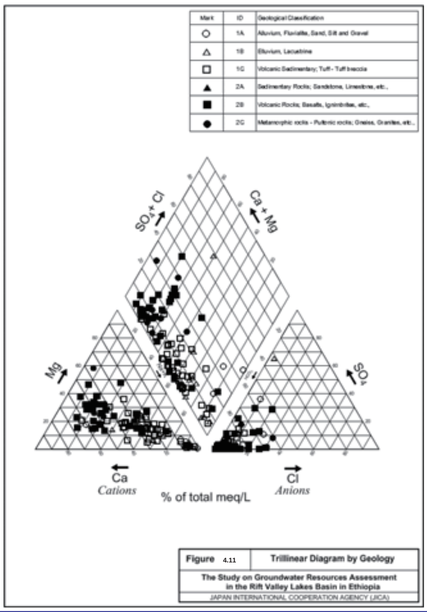
The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

1 Nature of groundwater by water quality analysis

1.2.2 Trilinear Diagram of the site by basin and geology



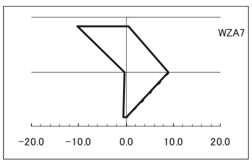


The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

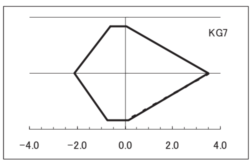
1 Nature of groundwater by water quality analysis

1.3 Hexa Diagram

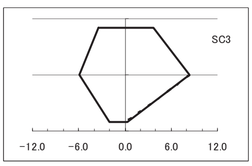
Na-HCO3 type

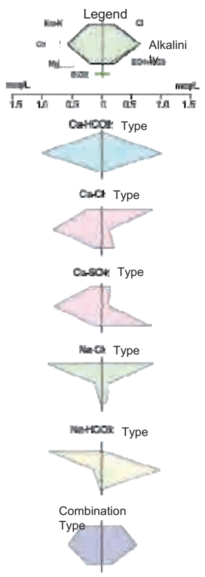


Ca-HCO3 type



Combination type





The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

1 Nature of groundwater by water quality analysis

1.4 Results and Interpretation

1. WQ by sub basins

Chew-Bahir sub-basin and Abaya-Chamo sub-basin are classified as Ca(HCO3)2 type → *shallow circulating groundwater*

Awassa sub-basin tends to have a pattern of NaHCO3 type
→ *deep groundwater in stagnant groundwater environments*

Ziway-Shalla sub-basin has both patterns of NaHCO3 and Ca(HCO3)2
→ *Mixture type of groundwater*

2. WQ by geology

Groundwater in sandstone, limestone, basalt, pyroclastics, granite and gneiss (2A-2C in the Figure) are categorized as Ca(HCO3)2 type

Groundwater in tuff, tuff breccia, lacustrine and alluvium is classified into NaHCO3 type and NaHCO3 +Ca(HCO3)2

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

2 Isotopic Characteristic of Groundwater in RV area

2.0 Isotope Analysis

1. 93 samples taken at the same place of other WQS
2. Immediately delivered to the AAU Lab
3. Classified by basin and geology

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

2 Isotopic Characteristic of Groundwater in RV area

2.1.1 Isotope Analysis Result

Code	BS_ID	AQ_ID	SOURCE OF SAMPLE	AQUIFER	ROCK FACIES	d ^{2}H (d D)	d ^{18}O
WZA-1	1	1C	Borehole	Qwbh	Basalt flow	-3.39	-2.55
WZA-2	1	2B	Borehole	N1_2n	Igninbrite, Welded tuff	-22.52	-4.74
WZA-3	1	1C	Borehole	Qwbh	Basalt flow	-2.89	-1.98
WZA-4	1	1C	Borehole	Qdi	Igninbrite, Tuff	-4.15	-2.48
WZA-5	1	1C	Borehole	Qdi	Igninbrite, Tuff	-19.63	-3.86
WZA-6	1	1C	Borehole	Qdi	Igninbrite, Tuff	-27.72	-5.21
WZA-7	1	1B	Borehole	Ql	Lacustrine	-16.09	-4.52
EZ-1	2	1B	Borehole	Ql	Lacustrine	3.17	-2.02
EZ-2	2	1B	Spring	Ql	Lacustrine	-1.59	-1.61
EZ-3	2	1B	Spring	Ql	Lacustrine	1.32	-1.01
EZ-4	2	2B	Borehole	Ql	Lacustrine	1.22	-1.19
EZ-5	2	1C	Borehole	Qwbh	Basalt flow	3.26	-0.93
EZ-6	2	1C	Spring	Qwbh	Basalt flow	5.19	-0.88
EZ-7	2	1B	Borehole	Ql	Lacustrine	5.93	-0.92
LS-1	3	1C	Spring	Qdi	Igninbrite, Tuff	6.26	-1.11
LS-2	3	1C	Spring	Qwpu	Pumice tuff, Tuff	-9.81	-3
LS-3	3	1C	Borehole	Qdi	Igninbrite, Tuff	-3.18	-2.12
LS-4	3	1C	Spring	NQs	Undivided Sediments	-17.92	-4.5
LS-5	3	2B	Borehole	N1_2n	Igninbrite, Welded tuff	24.53	4.66
LS-6	3	1C	Spring	Qdi	Igninbrite, Tuff	6.15	-2.51
LL-10	4	1C	Borehole	Qdp	Pyrocrastics	-1.11	-1.34
LL-11	4	1C	Spring	Qdi	Igninbrite, Tuff	-1.59	-1.61
LL-12	4	1C	Spring	Qdi	Igninbrite, Tuff	-6.7	-1.93
LL-7	4	1C	Borehole	Qdi	Igninbrite, Tuff	0.04	-2.04
LL-8	4	1C	Spring	Qdi	Igninbrite, Tuff	5.28	-0.38
LL-9	4	1C	Borehole	Qws	Silicica	0.97	-1.39
LA-1	5	1B	Borehole	Ql	Lacustrine	10.71	-0.28
LA-2	5	1C	Spring	Qdi	Igninbrite, Tuff	3.29	-2.02
LA-3	5	1B	Borehole	Ql	Lacustrine	22.64	2.09
LA-4	5	1B	Borehole	Ql	Lacustrine	3.32	-1.47
LA-5	5	1C	Borehole	Qws	Silicica	5.32	-0.81
LA-6	5	2B	Spring	N1_2n	Igninbrite, Welded tuff	-0.74	-2.48
LA-7	5	1C	Borehole	NQs	Undivided Sediments	2.28	-1.98

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

2 Isotopic Characteristic of Groundwater in RV area

2.1.2 Isotope Analysis Result

Code	BS_ID	AQ_ID	SOURCE OF SAMPLE	AQUIFER	ROCK FACIES	d ^{2}H (d D)	d ^{18}O
B-1 June 16/10	6	1C	spring	NQs	Undivided Sediments	10.11	-1.87
B-2 June 16/10	6	1C	Borehole	NQs	Undivided Sediments	1.99	-2.55
B-3	6	1C	Borehole	Qdi	Igninbrite, Tuff	-7.56	-2.51
B-4	6	1C	Borehole	Qdi	Igninbrite, Tuff	-0.94	-0.99
B-5	6	1C	Borehole	Qdi	Igninbrite, Tuff	-2.9	-1.38
B-6 June 09/10	6	1C	spring	Qvs	Volcanic Sediments	-15.23	-3.48
AG-1	7	1C	Borehole	NQs	Undivided Sediments	0.83	-2.55
AG-2	7	1C	Spring	Qwbp	Basalt	1.35	-2.54
AG-4	7	1C	Spring	NQs	Undivided Sediments	4.58	-1.76
AG-5	7	2B	Spring	Pv	Basalt	3.5	-1.99
AG-6	7	2B	Spring	Pv	Basalt	2.3	-1.83
GID-1	8	1C	Borehole	Qdp	Pyrocrastics	4.07	-2.31
GID-2	8	1C	Spring	Qdp	Pyrocrastics	4.07	-0.14
GID-3	8	1C	Borehole	Qdi	Igninbrite, Tuff	5.03	-0.16
GID-4	8	1C	Hand dug well	Qdi	Igninbrite, Tuff	5.01	-0.14
GID-5	8	2B	Borehole	N1_2n	Igninbrite, Welded tuff	5.05	-0.15
GID-6	8	2B	Spring	PNv	Igninbrite	5.02	-0.13
GID-7	8	2B	Borehole	PNv	Igninbrite	5.96	-1.05
(GID-8)Ag-3	7	1C	Borehole	NQs	Undivided Sediments	4.31	-1.04
KG-1	9	2B	Spring	Pv	Basalt	-8.49	-2.7
KG-2	9	2B	Spring	Pv	Basalt	-5.18	-2.42
KG-3	9	2B	Spring	PNv	Igninbrite	-2.89	-2.34
KG-4	9	2B	Spring	Pv	Basalt	-3.23	-2.62
KG-5	9	1A	Borehole	Qa	Alluvium	1.96	-1.42
KG-6	9	2B	Spring	Pv	Basalt	4.07	-2.31
KG-7	9	1C	Spring	Qwbp	Basalt	-0.42	-2.3

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

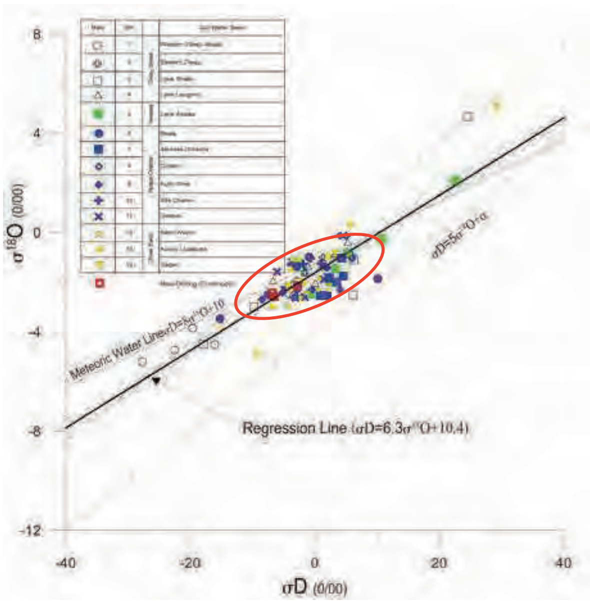
2 Isotopic Characteristic of Groundwater in RV area

2.1.3 Isotope Analysis Result

Code	BS_ID	AQ_ID	SOURCE OF SAMPLE	AQUIFER	ROCK FACIES	d^{2}H (d D)	d ^{18}O
SC-1	10	2B	Spring	Pv	Basalt	-0.71	-1.05
SC-2	10	1A	Spring	Qa	Alluvium	1.05	-1.27
SC-3	10	2B	Spring	Pv	Basalt	-4.74	-2.21
SC-4	10	1A	Borehole	Qa	Alluvium	-3.78	-1.27
SC-5	10	2B	Borehole	NMt	Basalt	-1.85	-1.27
SC-6	10	2B	Borehole	NMt	Basalt	-2.81	-1.27
GEL-1	11	2B	Spring	Pv	Basalt	-1.6	-2.6
GEL-2	11	2B	Borehole	PNv	Igninbrite	1.43	-1.89
GEL-3	11	2B	Borehole	PNv	Igninbrite	2.03	-1.79
GEL-4	11	2B	Borehole	Pv	Basalt	-3.16	-2.64
GEL-5	11	2C	Spring	Pcgn4	Gneiss	-6.07	-1.59
GEL-6	11	2B	Spring	Pv	Basalt	-3.7	-1.2
BW-1	12	2B	Spring	Pv	Basalt	0.5	-2.31
BW-2	12	2B	Spring	Pv	Basalt	-4.33	-2.93
BW-3	12	2C	Borehole	Pcgn4	Gneiss	0.68	-1.83
BW-4	12	2C	Spring	Pcgn3	Gneiss	-2.29	-2.6
BW-5	12	2B	Borehole	NPv	Basalt	-1.31	-2.45
BW-6	12	2B	Borehole	Pv	Basalt	-4.01	-2.31
BW-7	12	1A	Borehole	QHr	Fulviatile	2.27	-2.32
KL-1	13	1A	Borehole	Qa	Alluvium	-9.29	-4.81
KL-2	13	2C	Borehole	Pcgn1	Gneiss	-3.57	-1.04
KL-3	13	2B	Borehole	NMt	Basalt	-2.62	-1.05
KL-4	13	2C	Borehole	Pcgt4	Granite	-3.82	-1.46
KL-5	13	2C	Borehole	Pcgn1	Gneiss	2.09	-0.92
KL-6	13	2B	Borehole	NMt	Basalt	-6.78	-2.94
S-1	14	2B	Spring	NMt	Basalt	-4.43	-2.2
S-2	14	1B	Borehole	Qe	Ellivium	-1.72	-2.05
S-3	14	1B	Borehole	Qe	Ellivium	-2.34	-1.99
S-4	14	2C	Borehole	Pcgn4	Gneiss	29.21	5.04
S-5	14	2B	Spring	Pv	Basalt	5.69	0.26
S-6	14	2B	Borehole	NMt	Basalt	3.27	-0.84
RVS BH-2	15	1C	Borehole	Qdi	Sand, Gravel, Tuff	-2.81	-2.17
RVS BH-1	15	1C	Borehole		Sand, Gravel, Pumice	-6.82	-2.44
RVS BH-3	15	1C	Borehole		Tuff breccia	-6.53	-2.59

2 Isotopic Characteristic of Groundwater in RV area

2.2 Overall Plot of Isotope Analysis Result by Basin

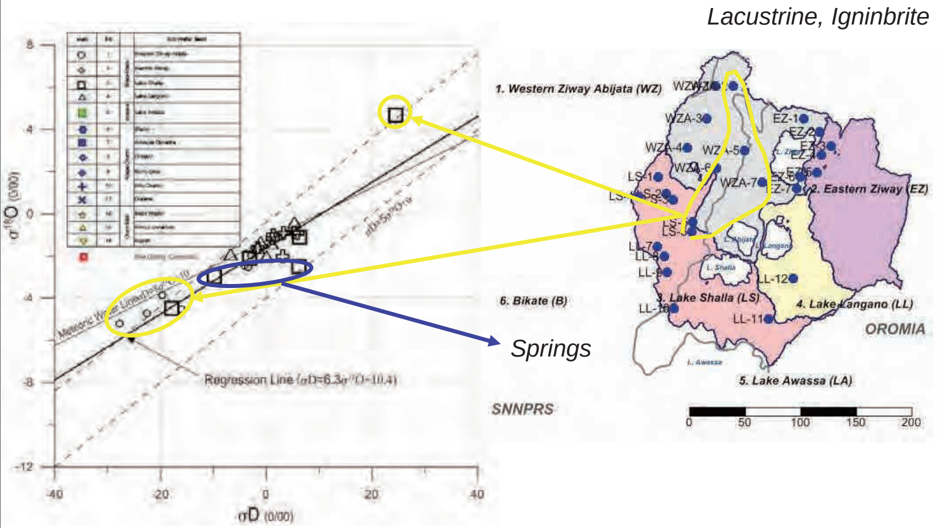


The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

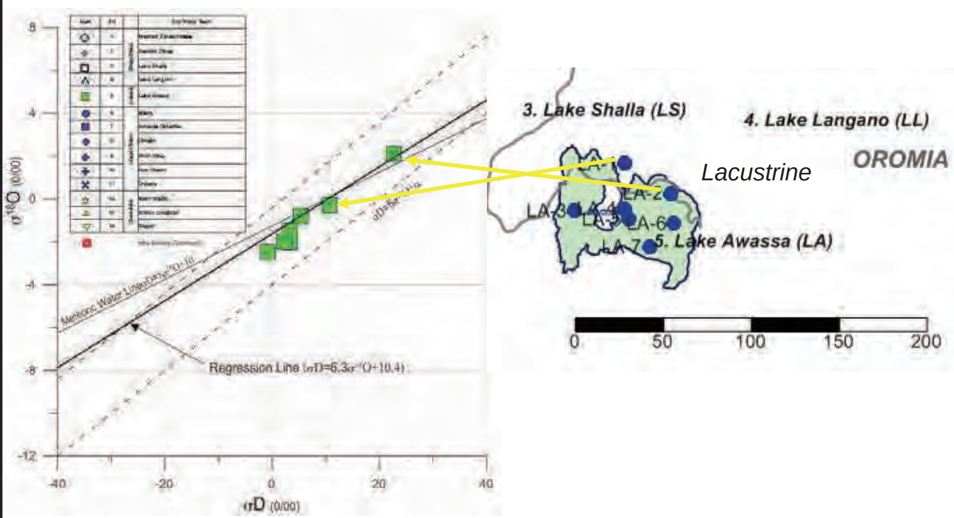
2 Isotopic Characteristic of Groundwater in RV area

2.2.1 Isotope Analysis Result by Basin (Ziway Shalla)



2 Isotopic Characteristic of Groundwater in RV area

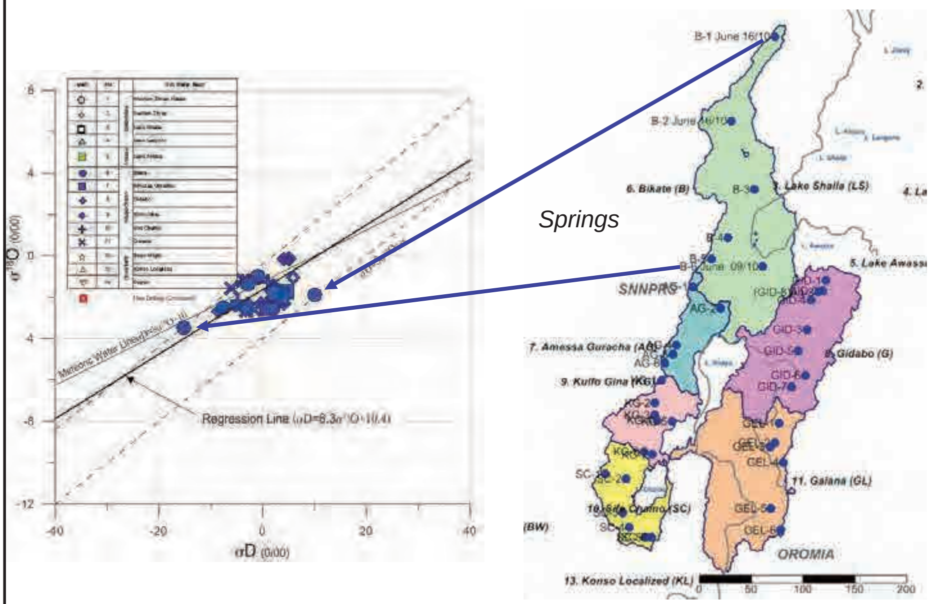
2.2.2 Isotope Analysis Result by Basin (Awassa)



WS-4 :同位体分析結果考察

2 Isotopic Characteristic of Groundwater in RV area

2.2.3 Isotope Analysis Result by Basin (Abaya Chomo)



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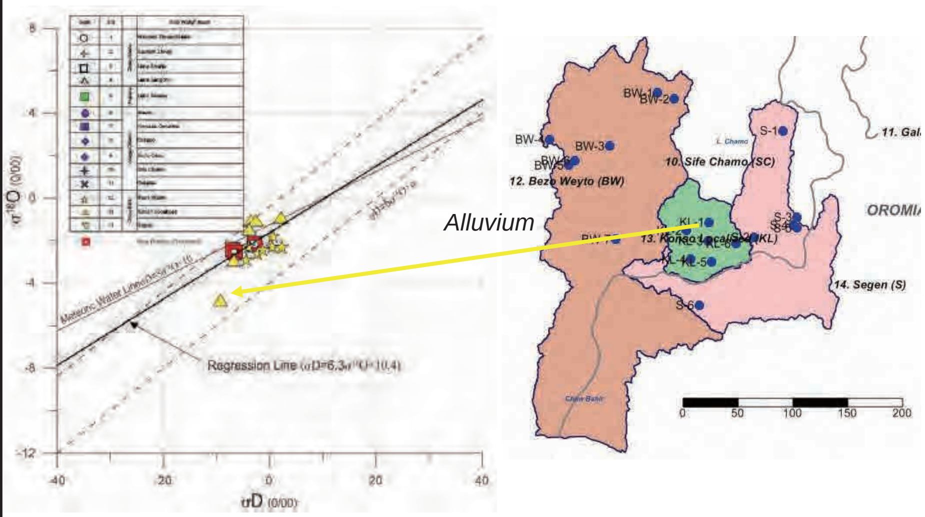
2 Isotopic Characteristic of Groundwater in RV area

2.2.4 Isotope Analysis Result by Basin (Chew Bahir)



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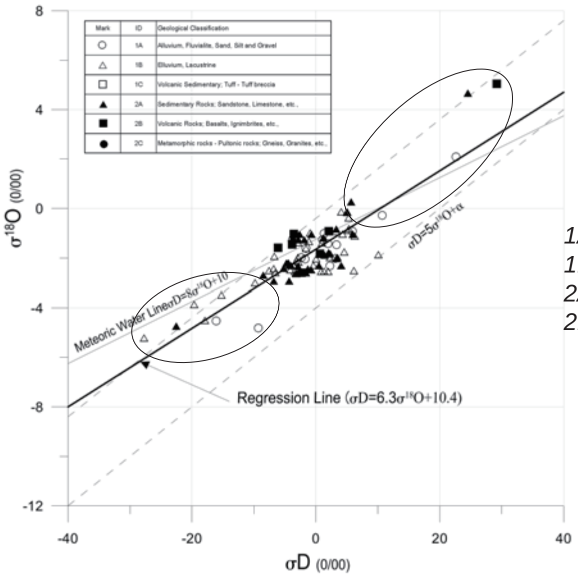
2 Isotopic Characteristic of Groundwater in RV area

2.3 Isotope Analysis by Geology



1A (Alluvium)
1B (Lacustrine)
2A (Sedimentary)
2B (Ignimbrite)

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

2 Isotopic Characteristic of Groundwater in RV area

2.4 Summary

1. **Most of the results fall into just below SMOW and/or along the meteoric line.**

2. **The abnormal values fall into the following criteria**

   By Basin
   - Northern side of Lake Ziway and Shalla and springs
   - Northern side of Lake Awassa
   - Springs at cliff edge at Bilate sub basin

   By Geology
   - Mostly in sediments and pyroclastics

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 :同位体分析結果考察

2 Isotopic Characteristic of Groundwater in RV area

2.5 Interpretation

1. Anomaly can be found in the Northern Lake side sediments

There are some similarities with hydrothermal activated area. The water in the sediments can be easily affected by the potential hydrothermal activity.

Assumption

Originally, isotopic components were the meteoric water, but was affected by hydrothermal water ? Relation with fluoride

2. Some springs at the escarpment has irregular values

High altitude springs has different isotope composition. Not big difference but there are some variety than other sources.

Assumption

The springs located at high elevation = ? Altitude affect or deferent water origin

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

3 Case of utilization of the isotope analysis in Japan

Estimation of the Sources and Flow System of Groundwater in Fuji-Gotenba Area by Stable Isotopic Analysis and Groundwater Flow Simulation

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The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 ：同位体分析結果考察

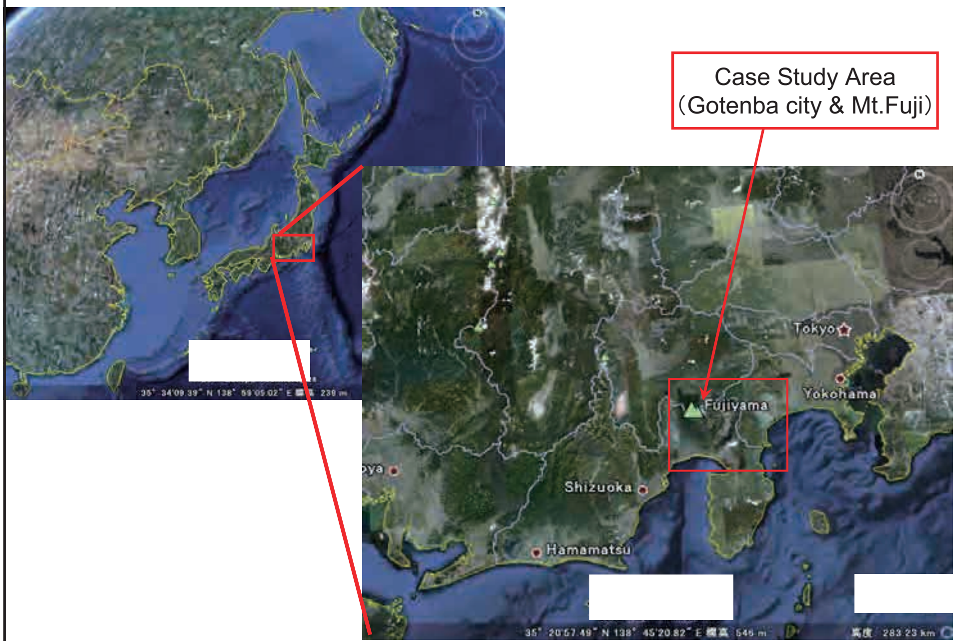
3 Case of utilization of the isotope analysis in Japan

Understanding the source and chemical character of the groundwater provides an important strategy for the quality management of mineral water and food materials. In order to identify a source and the flow paths of groundwater used for mineral water, the water quality and stable isotopes of hydrogen and oxygen of well water in Gotenba city were studied. The electrical conductivity and chemical character of sampled water are similar to those of well water and spring water discharged elsewhere around Mt. Fuji. The hydrogen and oxygen isotopic ratios of water samples indicate their origin to be solely meteoric and the oxygen isotopic ratios suggest that the groundwater mainly originated from the mountain-side of Mt. Fuji at altitudes of from 1500 m to 2300 m. A subsequent simulation of groundwater showed that the distribution of the total head and the Darcy velocity are down streamlines from mountain-sides toward the study area in Gotenba city. The altitudes of discharge obtained by the simulation are above 2000 m, and these correspond well with altitudes estimated from $\delta^{18}O$ values of the samples.

Keywords : Mt. Fuji ; groundwater ; stable isotopic analysis ; groundwater flow simulation.

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

3 Case of utilization of the isotope analysis in Japan



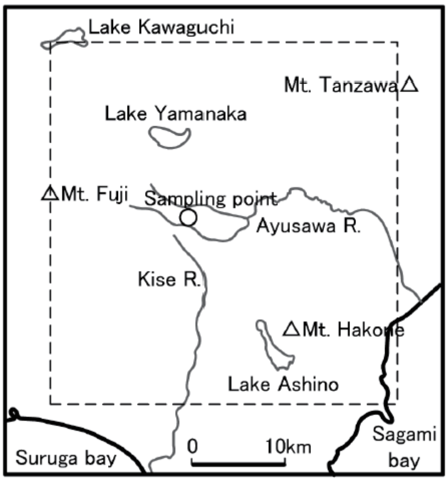
The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

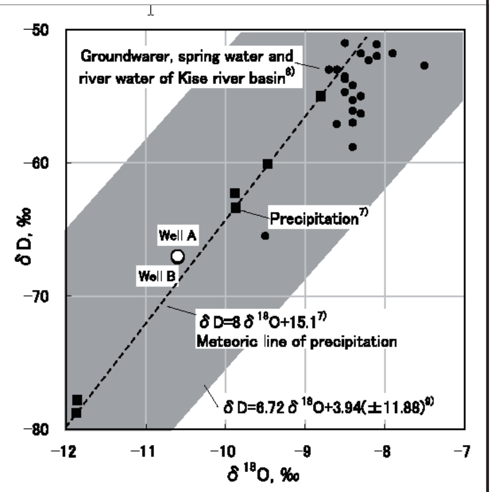
WS-4 ：同位体分析結果考察

3 Case of utilization of the isotope analysis in Japan

Case Study Area Outlook
(Sampling point lies in Gotenba city and very near to Mt.Fuji)

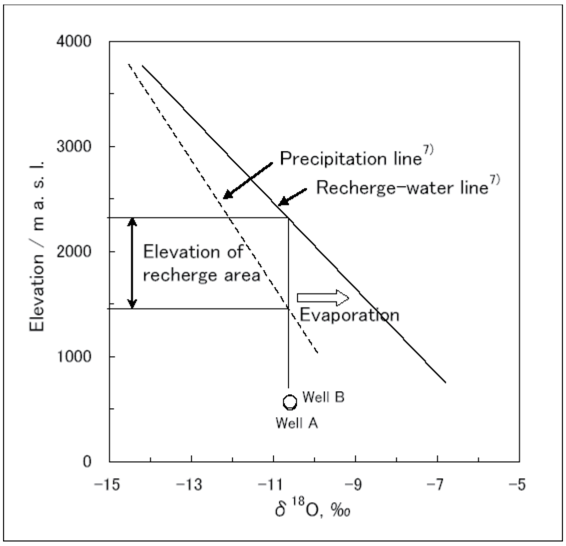
3 Case of utilization of the isotope analysis in Japan





WS-4 ：同位体分析結果考察

3 Case of utilization of the isotope analysis in Japan

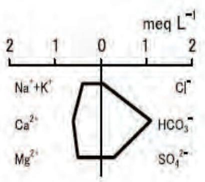


The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

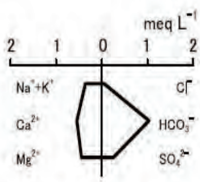
3 Case of utilization of the isotope analysis in Japan

Table 1 Chemical composition and stable isotope ratio of water samples

Sample name	pH	Tem, ℃	ORP/ mV	EC/ $mS\,m^{-1}$	Chemical composition/$mg\,L^{-1}$							Stable isotope ratio, ‰	
					Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	δD	$\delta^{18}O$
Well A	8.4	13.2	141	18.5	7.9	1.7	12	6.0	1.7	67	14	−67.1	−10.6
Well B	8.5	10.9	140	14.6	7.3	1.6	11	5.4	1.8	63	12	−67.0	−10.6



Groundwater from well A



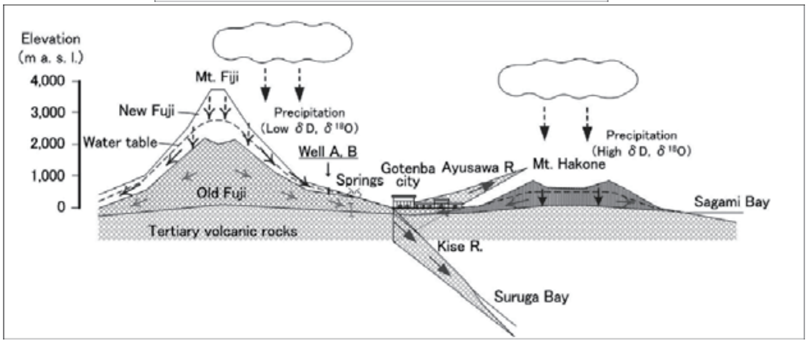
Groundwater from well B

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 :同位体分析結果考察

3 Case of utilization of the isotope analysis in Japan

Boundary conditions	Side and bottom	Impermeable
	Top (Ground surface)	Infiltration 1.9～8.8 mm d^{-1}
	River	Presser head : 0 m
Finite element method grid	Number of elements	67872
	Number of layers	6 (minimum thickness is 10 m)
Method of analysis	Saturated-unsaturated three-dimensional seepage analysis	



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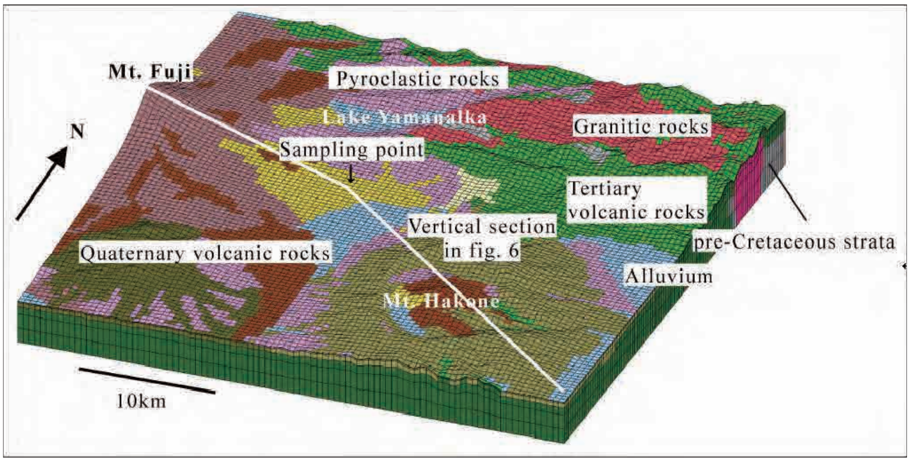

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WS-4 ：同位体分析結果考察

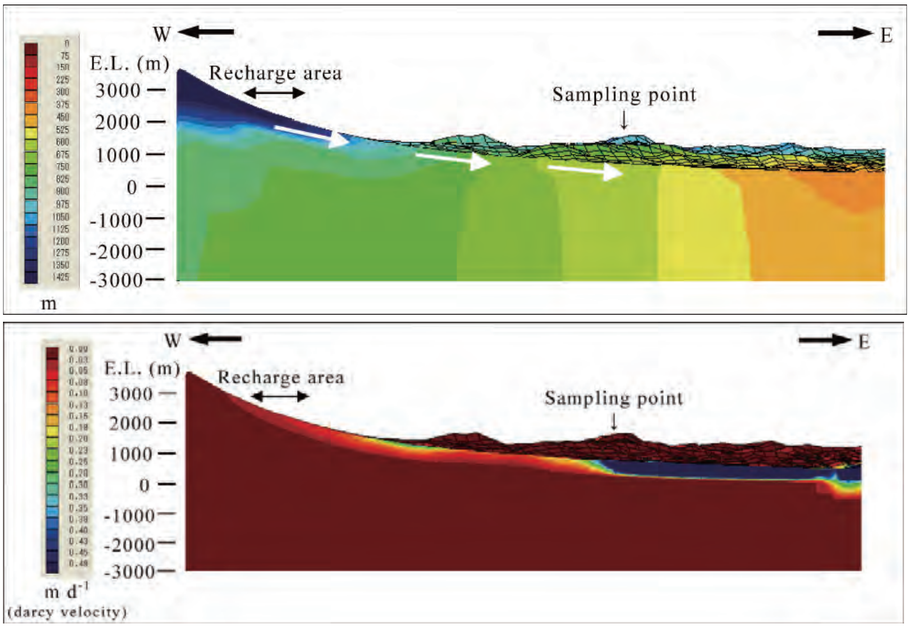
3 Case of utilization of the isotope analysis in Japan

Table 3 Geology and Property

Rock type	Hydraulic conductivity $k \times m\,s^{-1}$	Effective porosity, %
Alluvium	1.0×10^{-3}	15
Quaternary volcanic rocks	1.2×10^{-5} ~ 3.0×10^{-7}	15
Tertiary volcanic rocks	3.3×10^{-6}	2
Granitic rocks	4.0×10^{-7}	1
pre-Cretaceous strata	5.8×10^{-7}	1

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

3 Case of utilization of the isotope analysis in Japan



The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

WS-4 :同位体分析結果考察

END

THANK YOU FOR YOUR ATTENTION

The Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin

独立行政法人国際協力機構
国際航業株式会社

WS-5: GIS ガイドブック

The Study on Groundwater Resources Assessment
in the Rift Valley Lakes Basin

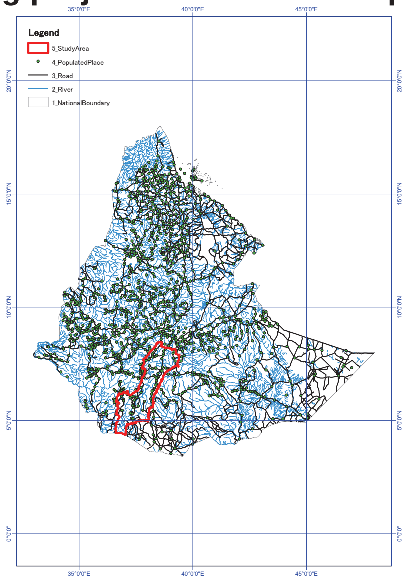
GIS Workshop

GIS utilization on groundwater development study

May, 2011

CONTENTS

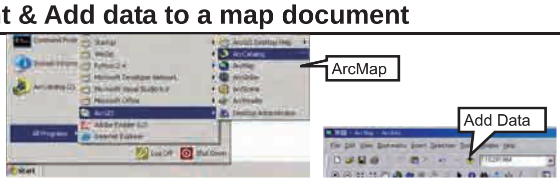
1. Case study 1: Making project site location map

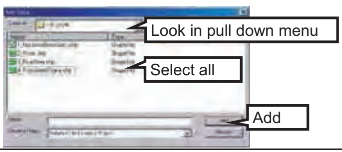


(Output example/image)

1.1. Start ArcMap and open a map document & Add data to a map document

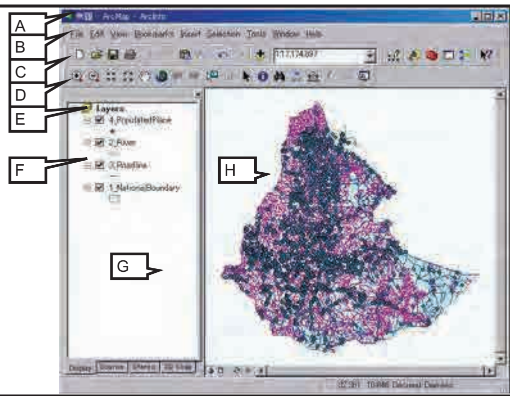
1) Click the Start menu, point to All Programs, Point to ArcGIS, and then click ArcMap.
2) Click the Add Data button.
3) Click the **Look in pull down menu**, point to the folder of **C:¥GIS¥001_shp**, and select the all item using shift key, and then click Add.





1.2. Get acquainted with the ArcMap interface

A) Title bar
B) Menu bar
C) Standard tool bar
D) Tools toolbar
E) Data frame: A data frame is a container for a map's layers.
F) Layer: A layer is an organized set of geographic features.
G) Table of contents: it contains a list of all the layers in ArcMap.
H) Map display

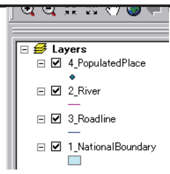


1.3. DCW (Digital Chart of the World): www.maproom.psu.edu/dcw/

- The Digital Chart of the World (DCW) is a comprehensive digital map of Earth. It is freely available as of 2006, although it has not been updated since 1992.
- The primary source for this database is the United States Defense Mapping Agency's (DMA) Operational Navigation Chart (ONC) 1:1,000,000 scale paper map series produced by the US, Australia, Canada, and the United Kingdom.
- The thematic layers of the DCW are: Political/Ocean (country boundaries), Populated Places (urbanized areas and points) ,Roads, Railroads, Drainage System, Hypsographic data, River and etc.
- The service is decommissioning the DCW due to inaccurate and out of date data. For up to date data; Natural Earth Data site. (url is http://www.naturalearthdata.com/)

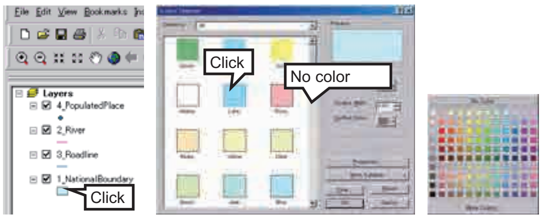
1.4. Layer control (Turn layers on and off)

1) In the table of contents, you can turn layers on and off by check/uncheck the check box
2) You can change the order layers by mouse-driven drag & drop. In ArcMap, bottom layer is placed the back side of the map display.



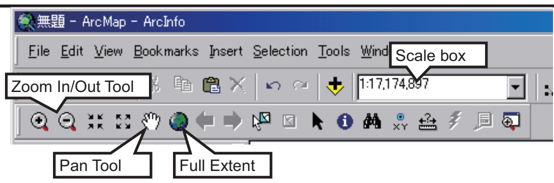
1.5. Symbolize a layer in ArcMap

1) In the table of contents, click the symbol box below the 1_NationalBoundary layer.
2) Click the pull down menu of fill color in options box, select the No color and click OK to apply the new symbol
3) Click the symbol below the River, select the River and click OK.
4) Click the symbol below the Road, select the Major Road and click OK.
5) Click the symbol below the Populated Places, select the Major Road and click OK.



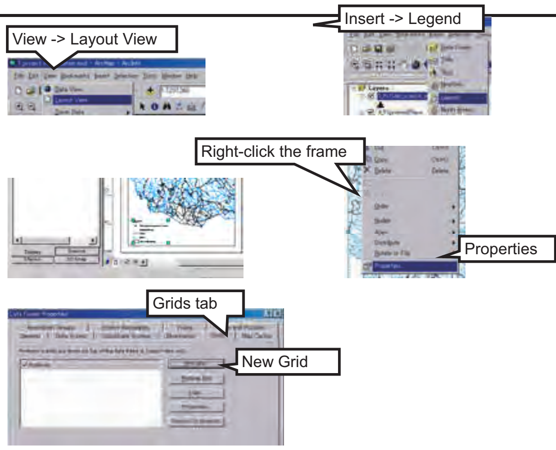
1.6. Explore scale in ArcMap

1) Look at the Map Scale box; you can confirm/change the scale of the map.
2) On the Tools of the toolbar, click the Zoom In tool, and then draw a rectangle with your mouse around the extent of the center.
3) Click the Pan Button; you can shift the map location.
4) Click the Full Extent button; you can see the full extent of the layers in the map display.



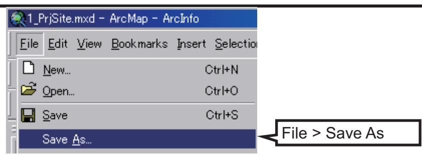
1.7. Map layout for printout

1) From the **View** menu, choose **Layout View**.
2) From the **Insert** menu, choose **Legend**, click Next 4 times, and click Finish.
3) You can see the legend box, move the box to left bottom side of the layout by mouse-driven drag & drop.
4) Right-click on the frame of map, click **Properties**, click **Grids tab**, click **New Grid** button, click Next 3 times, click Finish, click **Style** button, choose **Graticule with sub ticks**, click OK, and then click OK
5) You can see the grid of Lon-Lat. If you have a printer, you can printout from Print in File menu.



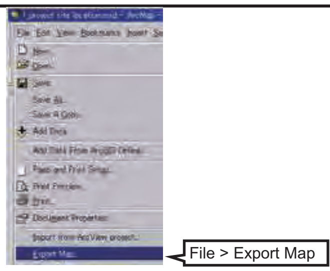
1.8. Save the map document

1) From the **File** menu, choose **Save As**.
2) In the dialog box, browse to your **C:¥GIS¥000_mxd** folder
3) In the File name box, type **1_StudyArea**, click Save, and close ArcMap
4) For check the saved file, browse to your **C:¥GIS¥000_mxd** folder, double-click **1_StudyArea.mxd**.



1.9. Export a map to PDF

1) From the **File** menu, choose **Export Map**.
2) In the dialog box, browse to **C:¥GIS¥002_pdf**, and choose the **PDF (*.pdf)** from pull-down of File type, and then click Save.
3) For check the saved file, browse to your **C:¥GIS¥002_pdf folder**, and double-click “1_StudyArea.pdf”, and then you can confirm the map by PDF. (required Acrobat Reader)



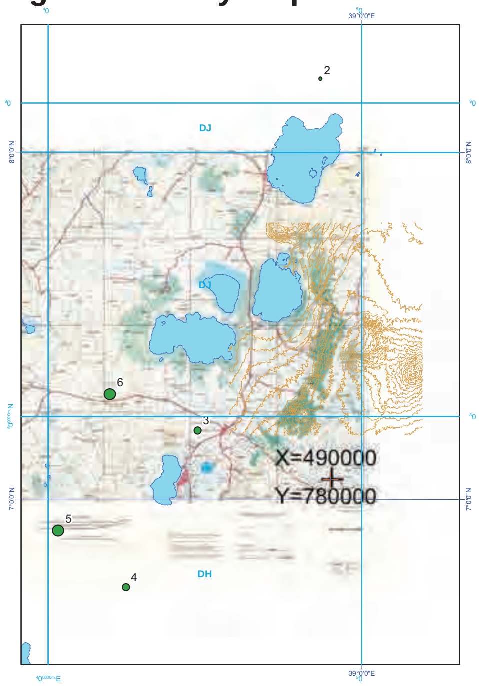
1.10. What is ArcGIS

■ ArcGIS is a suite consisting of a group of geographic information system (GIS) software products produced by ESRI. At the desktop GIS level, ArcGIS can include:
- **ArcReader**, which allows one to view and query maps created with the other Arc products;
- **ArcView**, which allows one to view spatial data, create layered maps, and perform basic spatial analysis;
- **ArcEditor** which, in addition to the functionality of ArcView, includes more advanced tools for manipulation of shapefiles and geodatabases; or
- **ArcInfo** which includes capabilities for data manipulation, editing, and analysis.

■ **Components**: ArcGIS Desktop consists of several integrated applications, including ArcMap, ArcCatalog, ArcToolbox, and etc..
- **ArcCatalog** is the data management application, used to browse datasets and files on one's computer, database, or other sources. In addition to showing what data is available, ArcCatalog also allows users to preview the data on a map. ArcCatalog also provides the ability to view and manage metadata for spatial datasets.
- **ArcMap** is the application used to view, edit and query geospatial data, and create maps. The ArcMap interface has two main sections, including a table of contents on the left and the data frame(s) which display the map. Items in the table of contents correspond with layers on the map.
- **ArcToolbox** contains geoprocessing, data conversion, and analysis tools. It is also possible to use batch processing with ArcToolbox, for frequently repeated tasks.

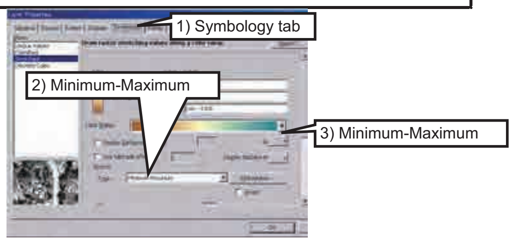
■ **Extensions**: There are a number of software extensions for ArcGIS Desktop to provide added functionality, including 3D Analyst, Spatial Analyst, Network Analyst and etc..
- **ArcGIS Spatial Analyst** is an extension to ArcGIS Desktop that provides powerful tools for comprehensive, raster-based spatial modeling and analysis. Using ArcGIS Spatial Analyst, you can derive new information from your existing data, analyze spatial relationships, build spatial models, and perform complex raster operations. Self-documenting models make it easy for others to understand the spatial analysis process applied, examine what-if scenarios, and compare results.

2. Case study2: Making field survey map



(Output example/image)

2.1. Explore DEM (Digital Elevation Model) data



1) Launch ArcMap
2) Click the **Add Data** button, and browse to **C:¥ GIS¥201_aster**, double-click **dem.img**
3) Click the **Add Data** button, and browse to **C:¥ GIS¥001_shp**, double-click **6_Lakes.shp.**
4) Double-click **dem.img** layer, click **Symbology tab**, choose **Minimum-Maximum** from the pull-down menu of Stretch-Type, and change the **color ramp** (for example brown-green type), and then click OK.
5) You can see the elevation on the map.

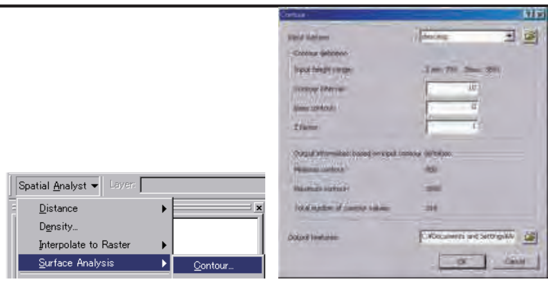
2.2. What is ASTER/DEM (Digital Elevation Model)?

- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a **Japanese** sensor which is one of five remote sensory devices on board the Terra satellite launched into Earth orbit by NASA in 1999. The instrument has been collecting surficial data since February 2000.
- ASTER provides high-resolution images of the Earth in 15 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meters. ASTER data are used to create detailed maps of surface temperature of land, emissivity, reflectance, and elevation.
- On 29 June 2009, the Global Digital Elevation Model (GDEM) was released to the public. A joint operation between NASA and **Japan's** Ministry of Economy, Trade and Industry (METI), the Global Digital Elevation Model is the most complete mapping of the earth ever made, covering 99% of its surface.

	ASTER GDEM	**SRTM3**	**GTOPO30**
Data source	ASTER	Space Shuttle Radar	Many institutions in the world
institution	METI/NASA	NASA/USGS	USGS
Start over	2009 -	2003 -	1996 -
times	2000 -	11days (2000)	
resolution	30m	90m	900m
accuracy	7m- 14m	10m	30m
cover	N83 - S83	N60 - S56	Global

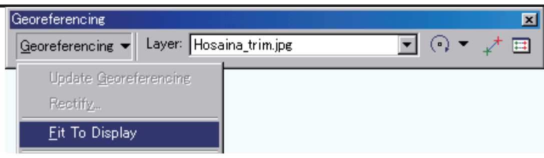
2.3. Making contour lines

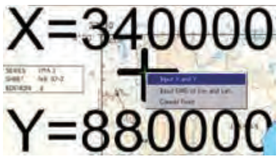
1) Activate the spatial analyst tool (if you can not see the tool bar, select Tools > Extensions, check the Spatial Analyst, right-click tool bar area, select the Spatial Analyst)
2) Cick the Spatial Analyst > Surface Analysts > Contour
3) In the Contour dialog, set the Input surface: **dem img**, Contour interval: **25,** click folder icon of Output features, browse **C:¥GIS¥301_analysis¥01_contour**, type **contour_100m**, click Save, click OK

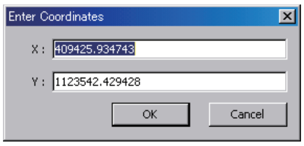


2.4. Geo-referencing

1) **Add Data** button, and browse to **C:¥ GIS¥104_scan**, click **TopoMap_Hosaina.jpg**, click Add.
2) From **View** > **Toolbars** , click **Georeferencing**, select “TopoMap_Hosaina.jpg” from pull-down menu of the toolbar, and then click **Georeferencing > Fit To Display**.
3) Click **Add Control Points**  in Georeferenceing toolbox
4) **Left-click** point of “X=340000, Y=880000” and **Right-click** > **Input X and Y** > input “X=340000, Y=880000”. And input the lower right point of “X=490000, Y=780000” using the same way.
5) Click **Georeferencing**, choose **Update Georeferencing** to save the result.
6) Save the map.

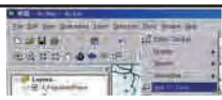


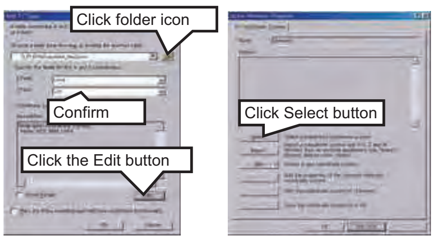


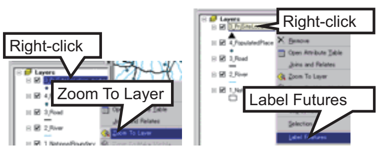


2.5. Plot drilling points location

1) From the Tools menu, choose **Add XY Data**
2) Click folder icon, browse to your **C:¥GIS¥003_db** folder, double-click **DrillingSite.xls,** and double-click **Sheet1$**.
3) Confirm **X** Field: **Easting**, **Y** Field: **Northing**.
4) Click the **Edit** button, click the Select button of the Spatial Reference Properties dialog, and Double-click **Projected Coordinate Systems** > **UTM** > **Other GCS** > **Adindan UTM 37N.prj**, then click OK, and then click OK.
5) Right-click **Sheet1$ Events** on the table of contents, click **Zoom To Layer.**
6) Right-click **Sheet1$ Events** on the table of contents, click **Label Futures**.
7) You can see the drilling points and name on the map.

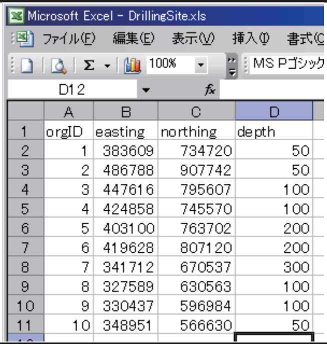






2.6. Add the attribute data to SHP (Database link)

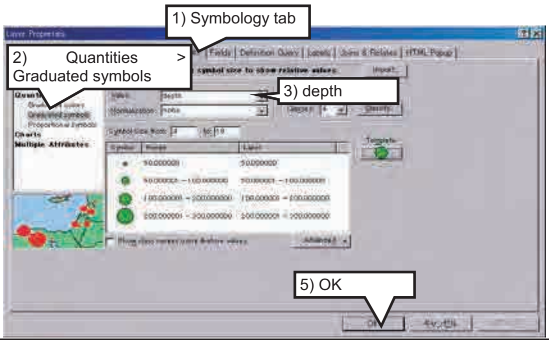
1) Right-click **Sheet1$ Events** on the table of contents, click **Remove**.
2) Browse to **C:¥GIS¥ 003_db**, and double-click **DrillingSite.xls.**
3) Type **depth** in cell of "**D1**" as a name of column (please make sure to do not use space and hyphen as a name of column)
4) Fill cells of the **depth** column any/given value.
5) From File menu, choose **Save**.
6) Shift ArcMap, import **DrillingSite.xls.** as a same way of 2.5



	A	B	C	D
1	orgID	easting	northing	depth
2	1	383609	734720	50
3	2	486788	907742	50
4	3	447616	795607	100
5	4	424858	745570	100
6	5	403100	763702	200
7	6	419628	807120	200
8	7	341712	670537	300
9	8	327589	630563	100
10	9	330437	596984	100
11	10	348951	566630	50

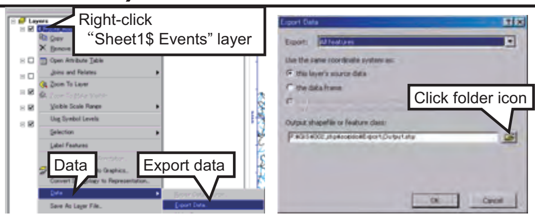
2.7. Thematic map

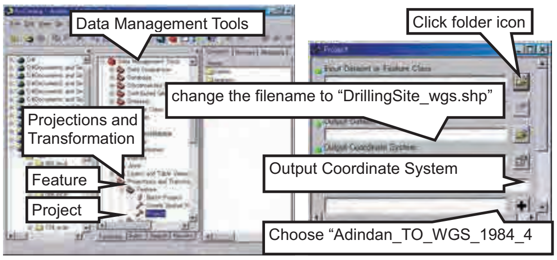
1) In the table of contents, double-click the layer name of **Sheet1$ Events**.
2) Click **Symbology** tab, click **Quantities>Graduated symbols**, choose **depth** from Value of Fields, and change the Classes to **3**, and then the click OK.
3) You can confirm the classification result on the map.

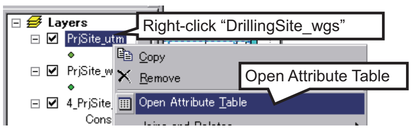


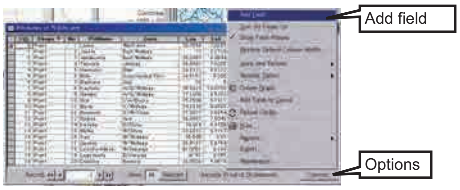
2.8. Export a layer to SHP & coordinate (WGS <> UTM)

1) Right-click **Sheet1$ Events** layer, point to **Data**, click **Export data.**
2) Click folder icon, browse to **C:¥GIS¥003_db**, type **DrillingSite_utm**, click Save, and click **OK**, the dialog will be display, click **No**.
3) Launch **ArcCatalog** (from Windows Start menu or ArcCatalog button in toolbar of ArcMap), click Arc Toolbox button in toolbar of ArcCatalog).
4) Double-click **Data Management Tools** > **Projections and Transformations** > **Feature** > **Project**
5) Click folder icon of the Input Dataset or Feature Class, browse **C:¥GIS¥003_db**, double-click **DrillingSite_utm.shp**, click the icon of Output Coordinate System, click **Select** button, double-click **Geographic Coordinate Systems** > **World** > **WGS 1984.prj**, and click OK, change the filename to **DrillingSite_wgs.shp**, choose **Adindan_TO_WGS_1984_4** form the pull-down of Geographic Transformation, click **OK**.
6) You can see **DrillingSite_wgs.shp**, add this SHP file to ArcMap **by mouse-driven drag & drop**.
7) Right-click **DrillingSite_wgs** layer, click **Open Attribute Table**, click **Options** button, click **Add field**, type "**lon**" as Name, choose **Double** as a Type, click OK

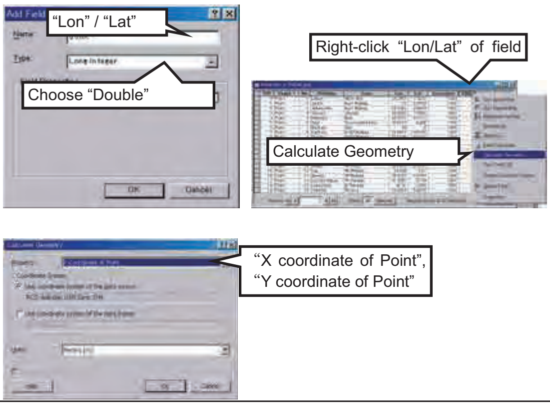






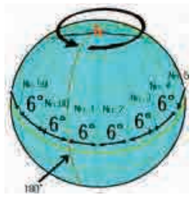


8) Right-click **"lon" of field title**, click **Calculate Geometry**, choose **X coordinate of Point** as a Property, click OK.
9) Add the "**lat**" in the same way.
10) You can see value of WGS.



2.9. Map Projection/Coordination

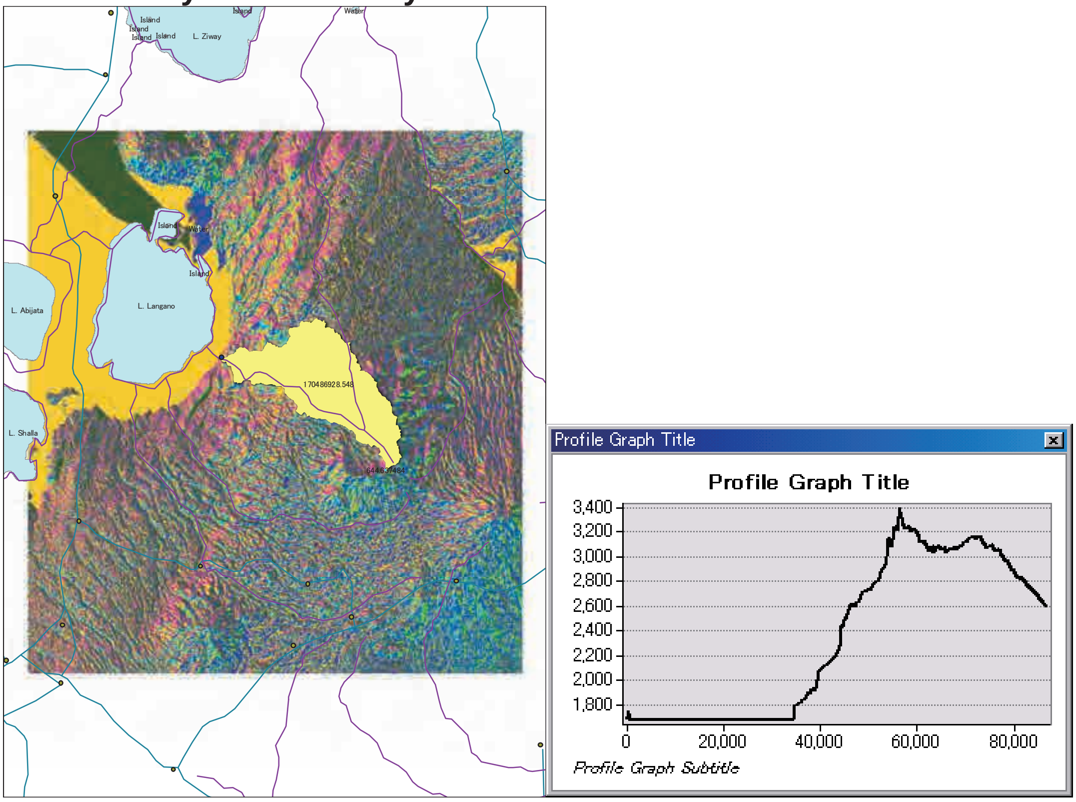
- Land Surface: Arc(Geoid)
  - Geodetic System
    - **Reference Ellipsoid; Spheroid Definition** (e.g. WGS84, Bessel)
    - **Datum**; **Centroid Definition** (e.g. WGS84, Tokyo)
- Map: Plane
  - **Map Projection** (e.g. Azimuthal , Conic, Cylindrical)
- Universal Transverse Mercator (Transverse Mercator Cylindrical Projection)
  - A whole surface of the Earth is divided by 6˚ in longitude.



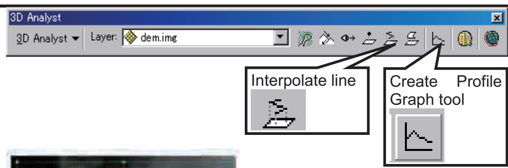
Zone No.	Longitude
No.1	180-186
No.37(Addis)	36-42
No.60	174-180

WS-5　GIS Guidebook

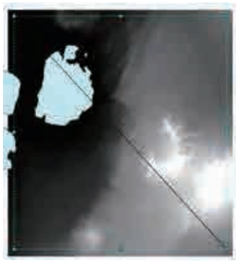
3. Case study 3: Basic analysis

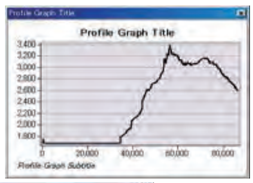


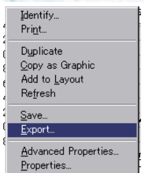
3.1. Cross section

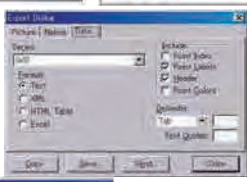


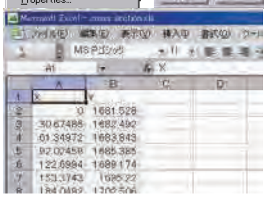
1) Launch ArcMap
2) Click the Add Data button, and browse to **C:¥ GIS¥001_shp,** double-click **6_Lakes.shp**.
3) Click the Add Data button, and browse to **C:¥ GIS¥ 203_aster_gdem,** select **dem.img**, and click Add, and then right-click **dem.img** on the table of contents, click **Zoom To Layer.**
4) From **View** > **Toolbars** , click **3D Analyst**, select “dem.img” from pull-down menu of the toolbar, and then click Interpolate line tool.
5) Draw the line on the dem. (to finish the drawing: double click)
6) Click the Create Profile Graph tool, you can see the cross section line as a graph.
7) Right click on the graph, and select export, click the Data tab, and select the Excel, click the Save button, browse to **C:¥ GIS¥003_db,** type **cross section** as a file name, click Save, and then click Close.
8) You can confirm the output result.





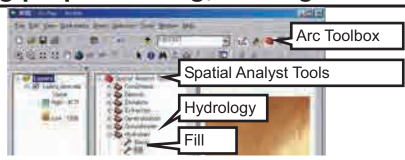






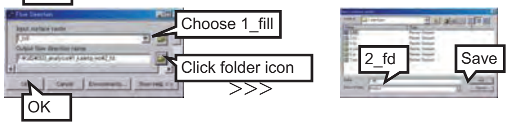
3.2. Make Watershed/Basin using DEM (including preprocessing, making stream)

1) Launch ArcMap
2) Click the Add Data button, and browse to **C:¥ GIS¥001_shp,** double-click **6_Lakes.shp**.
3) Click the Add Data button, and browse to **C:¥ GIS¥ 203_aster_gdem,** select **dem.img**, and click Add.
4) Click Arc Toolbox icon.

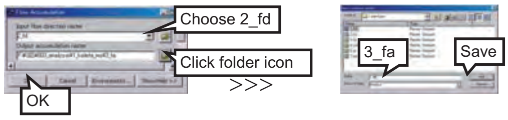


5) Double-click **Spatial Analyst Tools > Hydrology > Fill**, choose **dem.img** from the pull-down menu, click folder icon of the Output, browse **C:¥GIS¥301_analysis¥02_catchment,** type **1_fill** as a file name, and click Save, and then click OK.

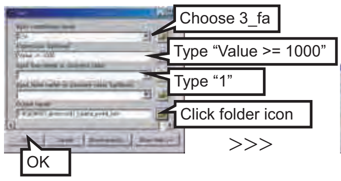
6) Double-click **Flow Direction** in the toolbox, choose **1_fill** from the pull-down, click folder icon of the Output, type **2_fd** as a file name, and click Save, and then click OK.



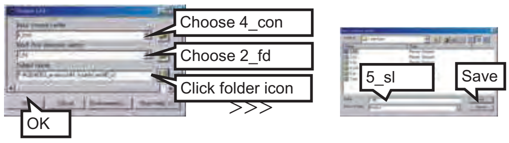
7) Double-click **Flow Accumulation** in the toolbox, choose **2_fd** from the pull-down, click folder icon of the Output, type **3_fa** as a file name, and click Save, and then click OK.

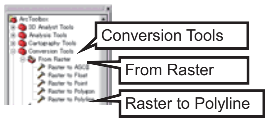


8) From the toolbox, double-click **Conditional** > **Con** in Spatial Analyst Tools, choose **3_fa** from the pull-down, type **"Value >= 1000"** in Expression box, type **"1"** in the box of Input true raster or constant value, click folder icon of the Output raster, type **4_con** as a file name, and click Save, and click OK.

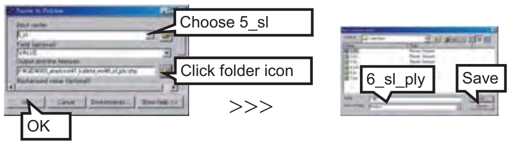


9) Double-click **Stream Link** in **Hydrology**, choose **4_con** from the pull-down menu of Input stream raster, choose **2_fd** from the pull-down menu of Input flow direction raster, click folder icon of the Output raster, type **5_sl** as a file name, and click Save, and click OK.

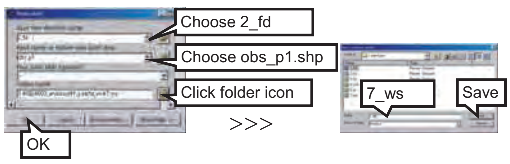




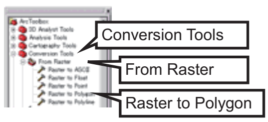
10) From Arc Toolbox, double-click **Conversion Tools > From Raster > Raster to Polyline**, choose **5_sl** from the pull-down menu of Input raster, click folder icon of the Output polyline features, browse **C:¥GIS¥301_analysis¥02_catchment**, type **6_sl_ply** as a file name, and click Save, and then click OK.

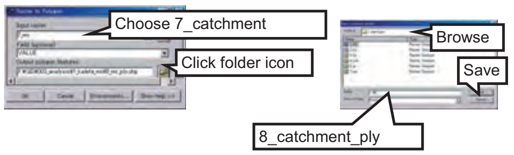


11) Click the Add Data button, and browse to **C:¥ GIS¥301_analysis¥02_catchment**, double-click **101_obs_point.shp**.
12) Double-click **Watershed** in Hydrology, choose **2_fd** from the pull-down menu of Input flow direction raster, choose **101_obs_point** from the pull-down menu of Input raster or feature, click folder icon of the Output raster, browse **C:¥GIS¥301_analysis¥02_catchment**, type **7_catchment** as a file name, and click Save, and then click OK.



13) From Arc Toolbox, double-click **Conversion Tools > From Raster > Raster to Polygon**, choose**7_catchment** from the pull-down, click folder icon of the Output, browse

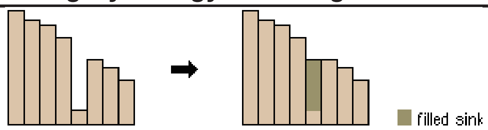




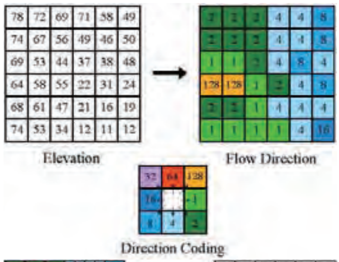
C:¥GIS¥301_analysis¥02_catchment, type **8_catchment_ply** as a file name, click Save, and click OK.

3.3. Making process of watershed boundary using Hydrology Modeling

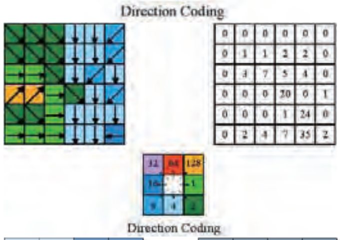
1) **The Digital Elevation Model (DEM)** is a cell-based raster data referring to the surface of the Earth. Each cell contains an elevation data which represents the elevation of the cell.
2) **Fill Sinks:** Sinks, which affects internal drainage, may cause undesirable result when calculating flow direction. Therefore it is required to fill sinks in order to create depressionless DEM.



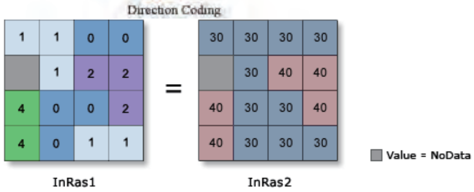
3) **Flow Direction:** Flow direction in each cell of the DEM is determined and the directions are referred by 8 numbers ranging 1 to 128. Direction data is stored in each cell as a number correlated to its direction.



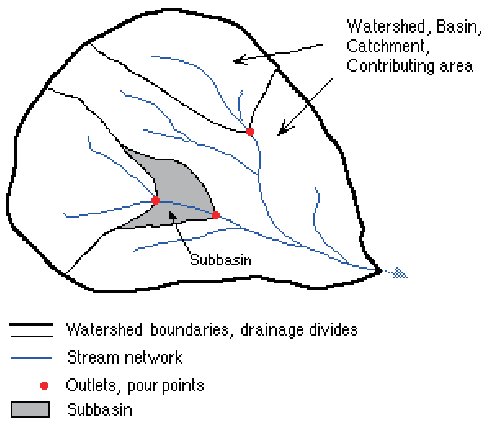
4) **Flow Accumulation:** The Flow Accumulation dialog calculates accumulated flow based on the raster data of the Flow Direction. The accumulated flow is the accumulated weight of all cells flowing into each down-slope cell.



5) **Conditional:** Performs a conditional if/else evaluation on each of the input cells of an input raster.



6) **Stream Network:** The Stream Network dialog provides a stream in case of precipitation as a shape file (i. e. file form of figures for the ArcGIS) based on the Flow Direction and the Flow Accumulation.
7) **Watershed:** This area is normally defined as the total area flowing to a given outlet or pour point. These areas are the output of the Watershed tool. The boundary between two watersheds is referred to as a watershed boundary or drainage divide. An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. Source cells may be features, such as dams or stream gauges, for which you want to determine characteristics of the contributing area.

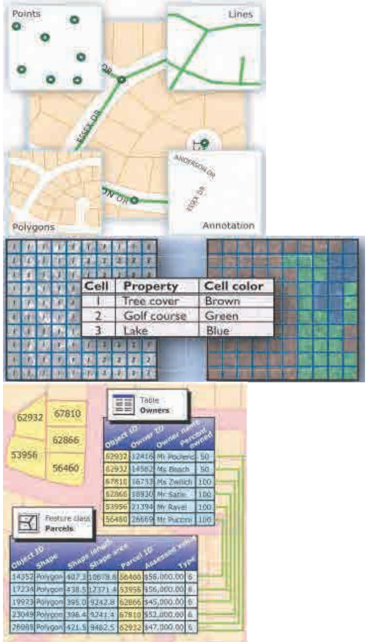


3.4. Calculation of catchment area

9) Right-click **8_catchment_ply** layer, click Open Attribute table, click Add field from Option button, type “area” in Name box, choose Double from pull-down menu of Type, and then click OK.
10) Right-click column name of area, click Calculate Geometry, choose Area from pull-down menu of Property, chose Square Kilometers from pull-down menu of Units, and then click OK.

3.5.　Types of geographic datasets

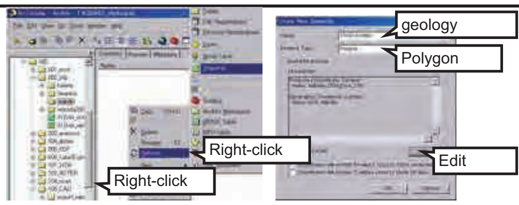
- **Vector**
  - Points
  - Lines
  - Polygons
- **Raster**
- **Associated　attribute　tables**



4. Case study 4: Data convert from hardcopy to softcopy (digitizing)

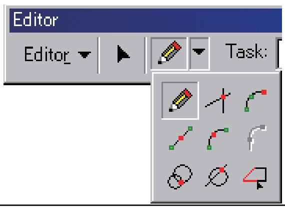
4.1. Making SHP file (polygon)

1) Launch **ArcCatalog**, browse to **C:¥GIS¥301_analysis¥03_geology**, right-click on vacant area of contents window, point to **New**, click **Shapefile**, type **geology** as a Name, choose **polygon** as Feature Type, click **Edit** button, click **Select** button, double-click **Projected Coordinate Systems** > **UTM** > **Other GCS** > **Adindan UTM Zone 37N.prj**, click OK x 2.



4.2. Digitizing

1) Launch ArcMap
2) Click the Add Data button, and browse to **C:¥GIS¥104_scan,** select **Geologicalmap_Awasa.jpg**, and click Add**.**
3) Click the Add Data button, and browse to **C:¥GIS¥ 301_analysis¥03_geology,** select **geology.shp.**
4) Set the scale 1:100,000
5) From **View** > **Toolbars** , click **Editor**.
6) Click **Editor button** on Editor tool bar, click **Sketch tool** icon on Editor Toolbar, and select **geology** from the pull-down menu of the Editor toolbar
7) **Draw a polygon**: Trace a boundary line of a geology by click with your mouse
8) **Close a polygon**: when you close the traced polygon: double click
9) **Trace Tool**: Click the sketch tool on Editor Toolbar, and select trace tool. Select edit tool, and then click a polygon which you want to trace it.
10) Save: Click **Editor** on Editor toolbar > **Stop Editing**, click **Yes** to Save the edits.



4.3. Input the attribute data to the traced polygon

1) Right-click **geology** layer, click **Open Attribute Table**, click **Options** button, click **Add field**, type **"name"** as Name, choose **Text** as a Type, click OK
2) Double-click **geology** layer, click **Labels** tab, change the Label Field from **Id** to **name**, and click OK, and then right-click **geology** layer > select **Label Features**.
3) Click **Editor button** on Editor tool bar, click edit tool, click a polygon which you want to it, and then type geology name to the name column.
4) Double-click **geology** layer, click **Symbology,** select the Categories > Unique values > Value Field: name, click Add All Values > OK.
5) You can change the color from table of contents.

WS-6：地下水シミュレーション

THCHICAL SEMENAR ON GROUNDWATER SIMULATION

Dr. Lei Peifeng
JICA Study Team

2011.05.25

1

Main Topics of Today's Presentation

- Conception and theory about groundwater system
- History of groundwater simulation
- Methods and program of groundwater simulation
- Function and main packages in Modflow based programs
- Basic process for groundwater model creation
- Case study

2

WS-6 : 地下水シミュレーション

Profile of the lecturer

Name : Lei Peifeng

Age : 55

Occupation : Chief Hydrogeologist,
Kokusai Kogyo Co., Ltd.(KKC)

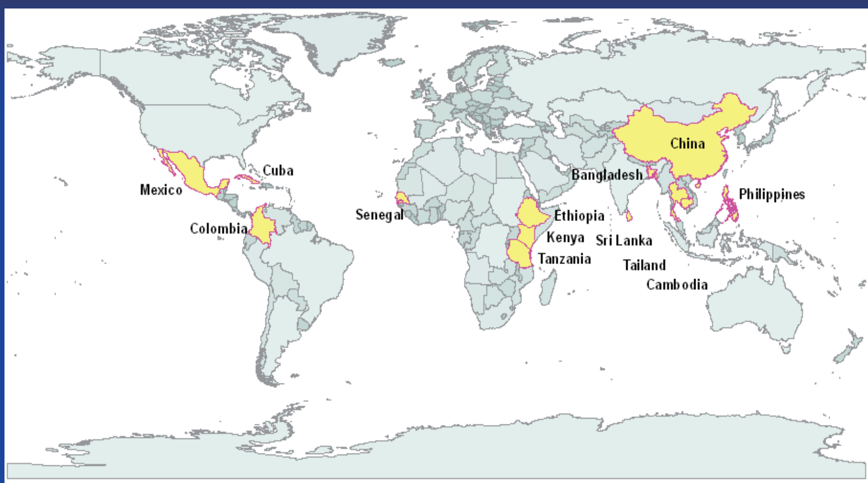
Academic background:
Mar.1982: Graduated from Changchun Geology Institute, China
Mar.1988: Agriculture Doctorate in Tsukuba University, .Japan

Employment record:
1988-1990: Beijing Vegetables Research Center ,China
1990-1993: Foreigner Expert Bureau of China
1994-Now: Kokusai Kogyo Co., Ltd

Overseas working track:
Philippine, China, Thailand, Tanzania, Cambodia, Bangladesh, Mexico, Sri Lanka, Colombia, Ethiopia, Kenya, Senegal, Cuba

3

Overseas working track



4

WS-6 ： 地下水シミュレーション

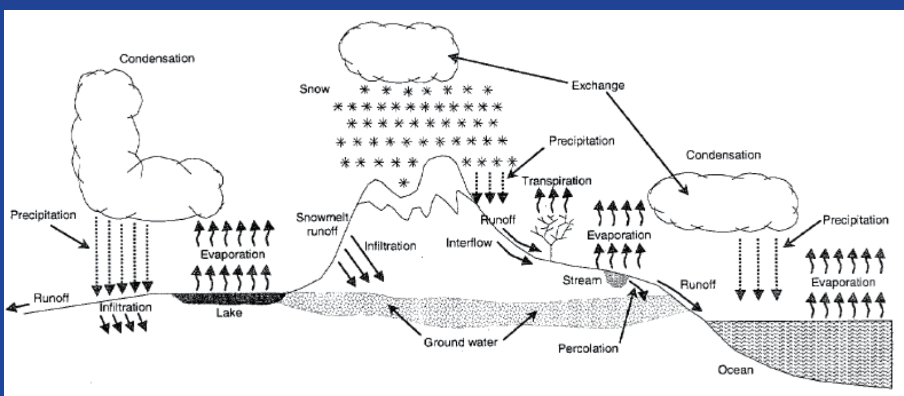
THCHICAL SEMENAR ON

GROUNDWATER SIMULATION

Part 1
Conception and Theory
about Groundwater System

5

Concept of Hydrologic Circle



Graphic Source: US Department of Transportation

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WS-6 : 地下水シミュレーション

Concept of Hydrologic Circle in Land Area

Image from: http://www.eurogeosurveys.org/

7

Water in the World

	Water Amount (km³)	Residence time
Ocean	1,349,929,000 (97.5%)	3,200 years
Iceberg	24,230,000 (1.75%)	9,600 years
Groundwater	10,100,000 (0.73%)	830 years
Soil water	25,000 (0.00 %)	0.3 e years
Lakes	219,000 (0.02%)	Several or several hundreds years
Rivers	1200 (0.00%)	13 days
Water vapor	13,000 (0.00%)	10 days
Total	**1,384,517,200**	

8

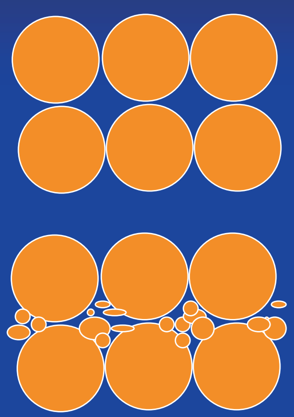
What is Groundwater?

Water stored in pores, fractures, and small cavities below the ground surface.

Groundwater flows through pores in soil and through fractures in rock.

9

Grain Size Sorting Effects on Porosity



Well Sorted

Poorly Sorted

10

Porosity

$$p = \frac{W}{V} \times 100 \quad (\%)$$

V : total volume of soil or rock,
W: volume of space in soil or rock,
p: porosity in %.

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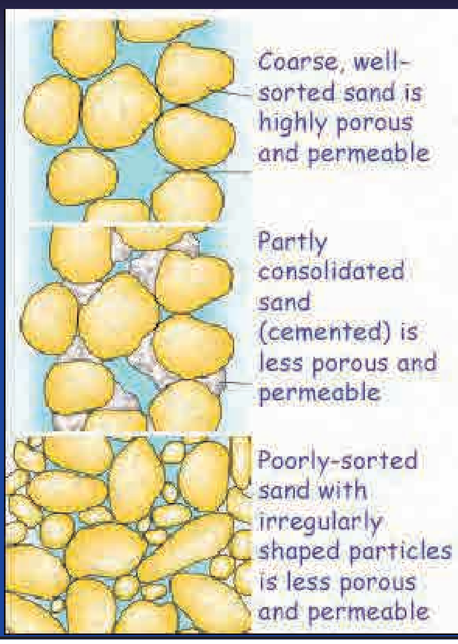
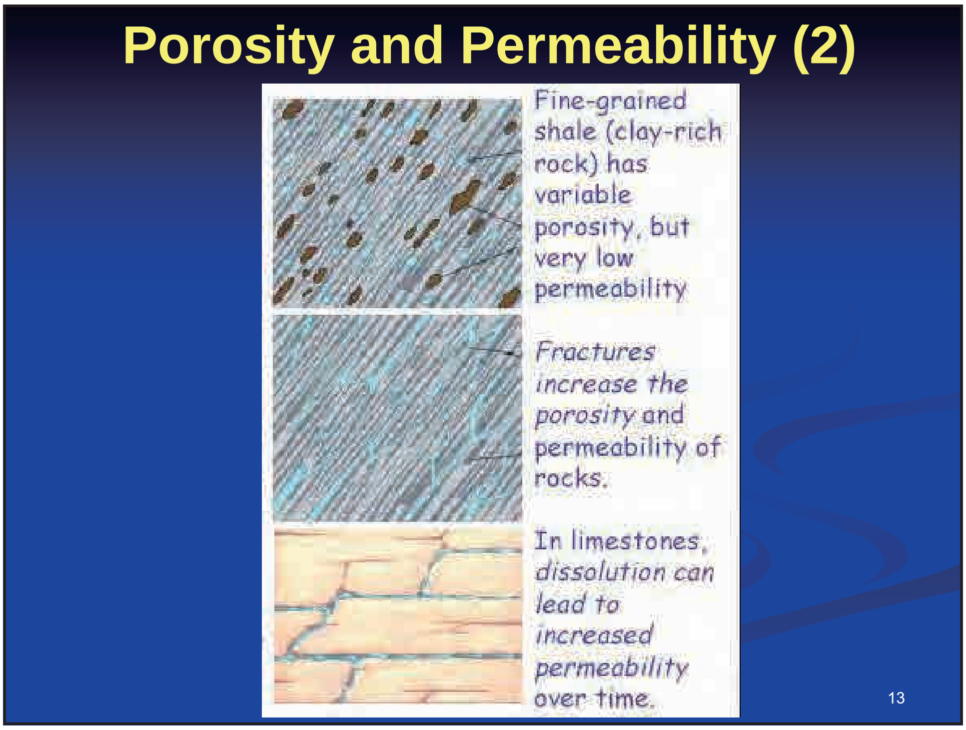
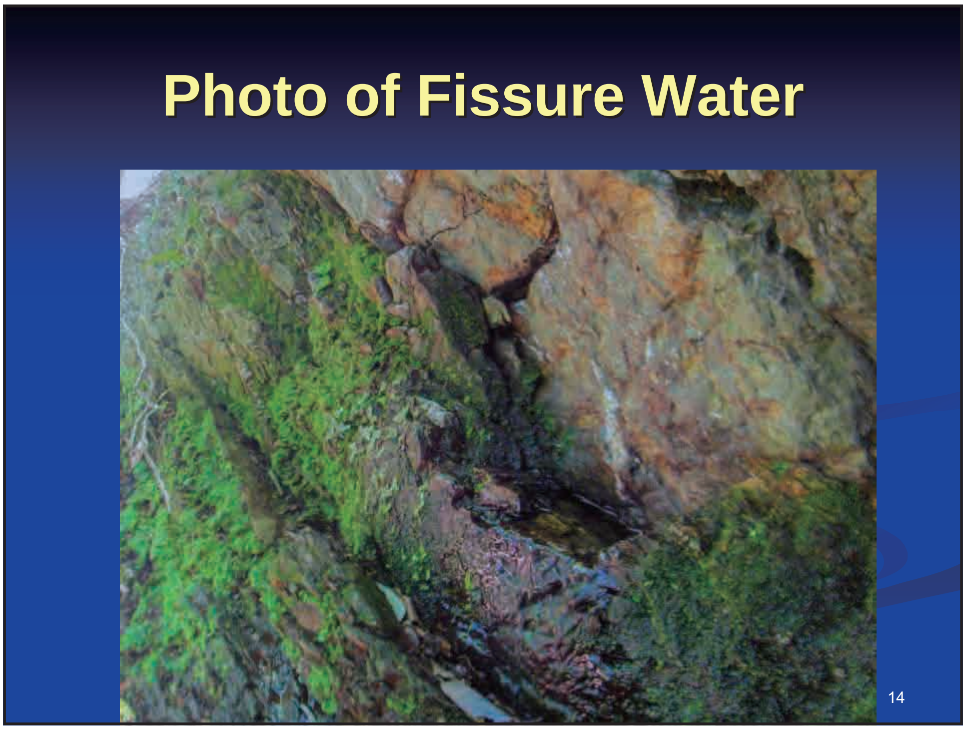
Porosity and Permeability (1)



12

WS-6 ： 地下水シミュレーション





Typical Porosity Values

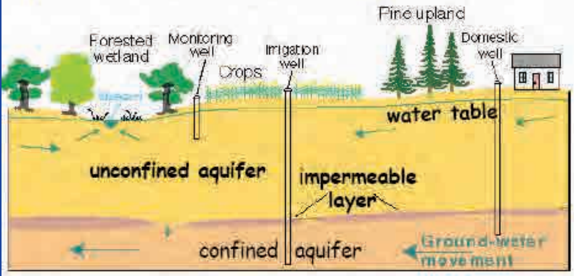
Well sorted sand	0.25-0.50	(25-50%)
Poorly sorted sand	0.20-0.35	(20-35%)
Silt	0.35-0.50	(35-50%)
Clay	0.35-0.60	(35-60%)
Till	0.10-0.30	(10-30%)
Rock	0-0.02	(0-2%)
Weathered Rock	0.0-0.60	(0-60%)

15

What is Aquifer?

An *aquifer* is a geological unit that is capable of producing a useful quantity of water.

Such a geological unit must have sufficient water storage capacity (*porosity*) and must allow for the movement of that water (*permeability* or transmissivity).



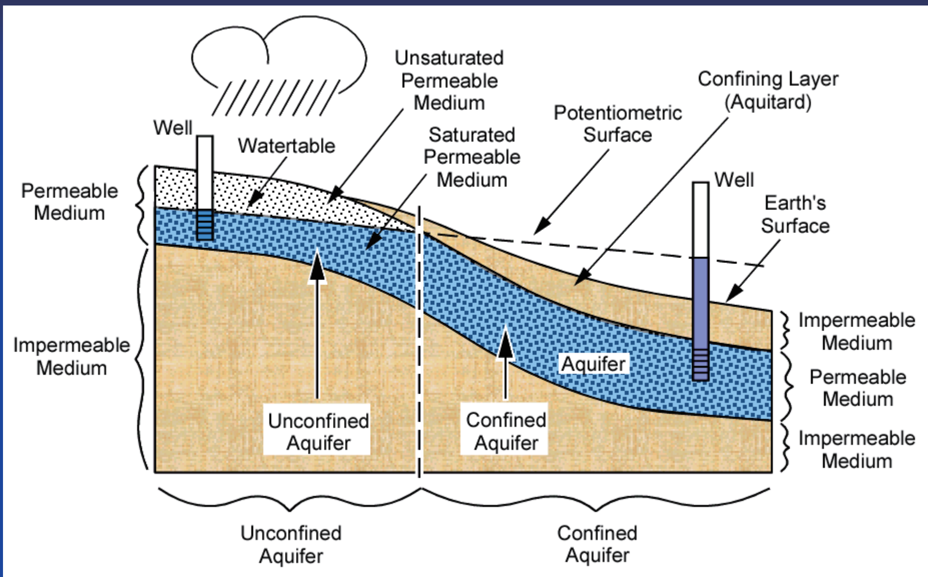
Types of aquifers

- *unconfined* (or water table) aquifer; lower bound is an impermeable layer, upper bound is top of the saturated zone; water in well rises to the water table.

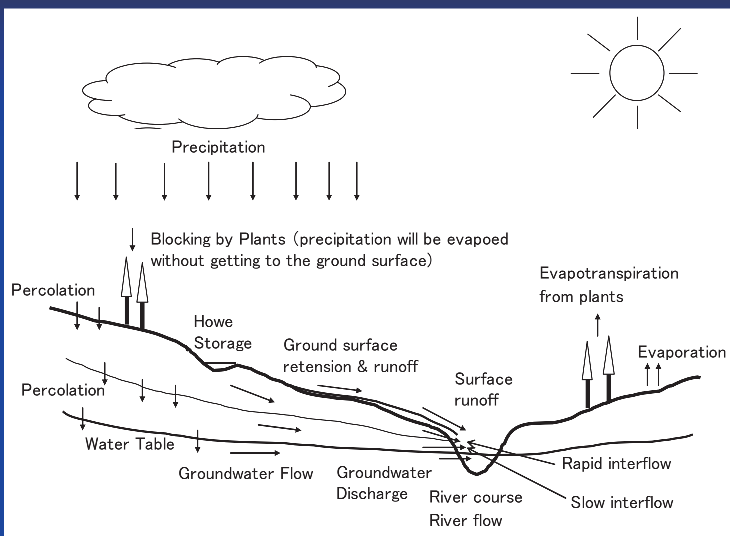
- *confined* aquifer; lower and upper bounds are impermeable layers; water in well rises above top of aquifer layer (i.e., top impermeable layer keeps water under pressure).

WS-6 ： 地下水シミュレーション

Confined and Unconfined Aquifers



Recharge, Flow and Discharge



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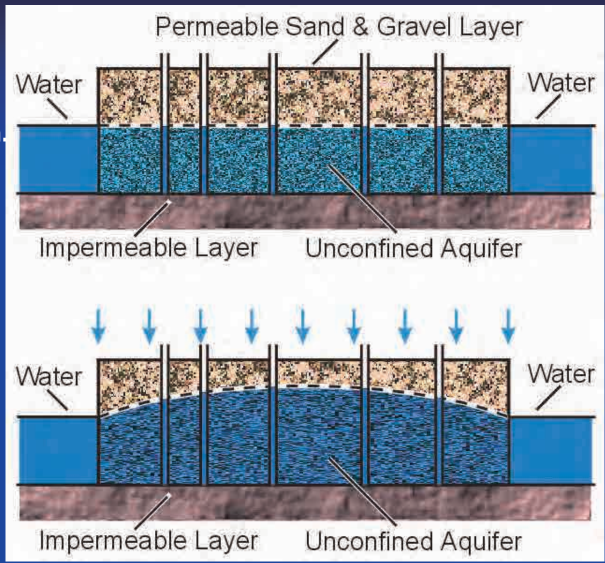
WS-6 : 地下水シミュレーション

Effect of Precipitation on the Watertable with No Initial Flow.

Water table:
No infiltration.

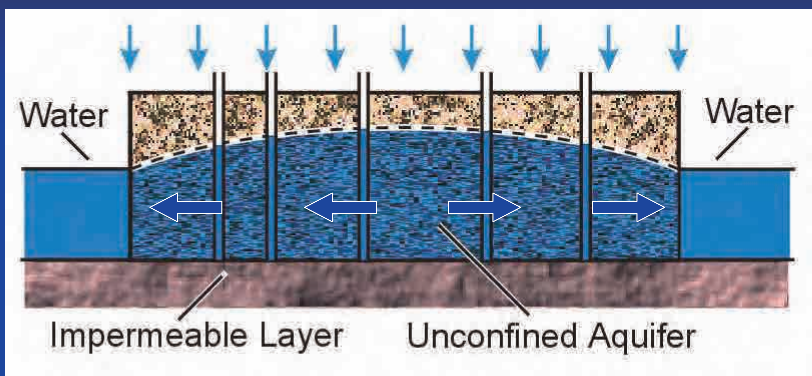
Water table:
Infiltration.



The watertable with and without infiltration (precipitation).

19

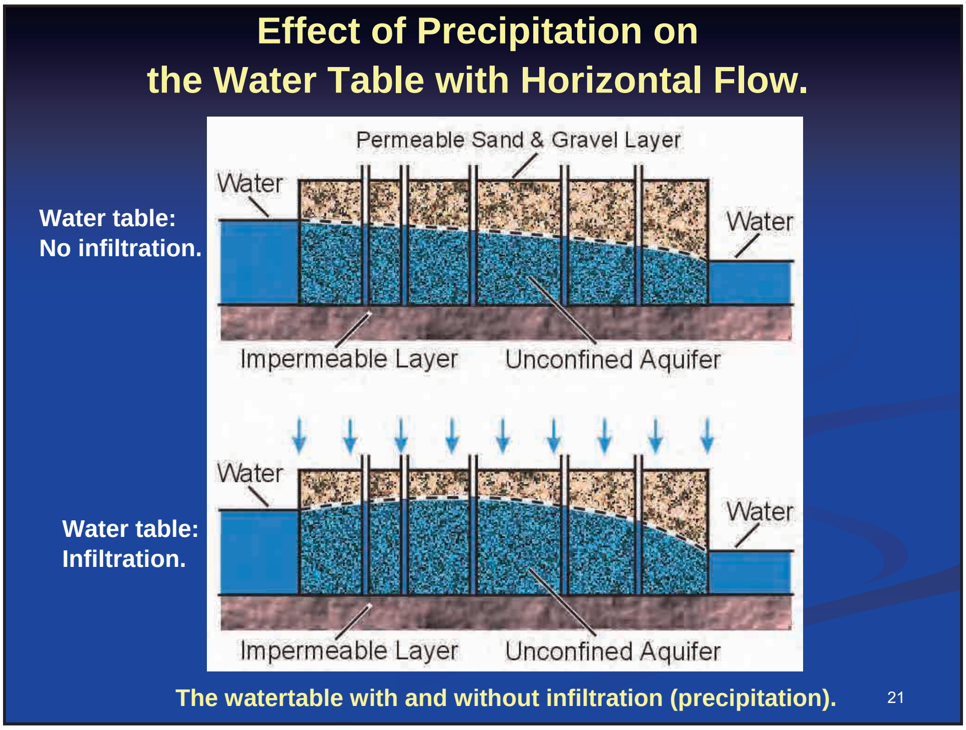
Looking in Detail at Local Flow Directions

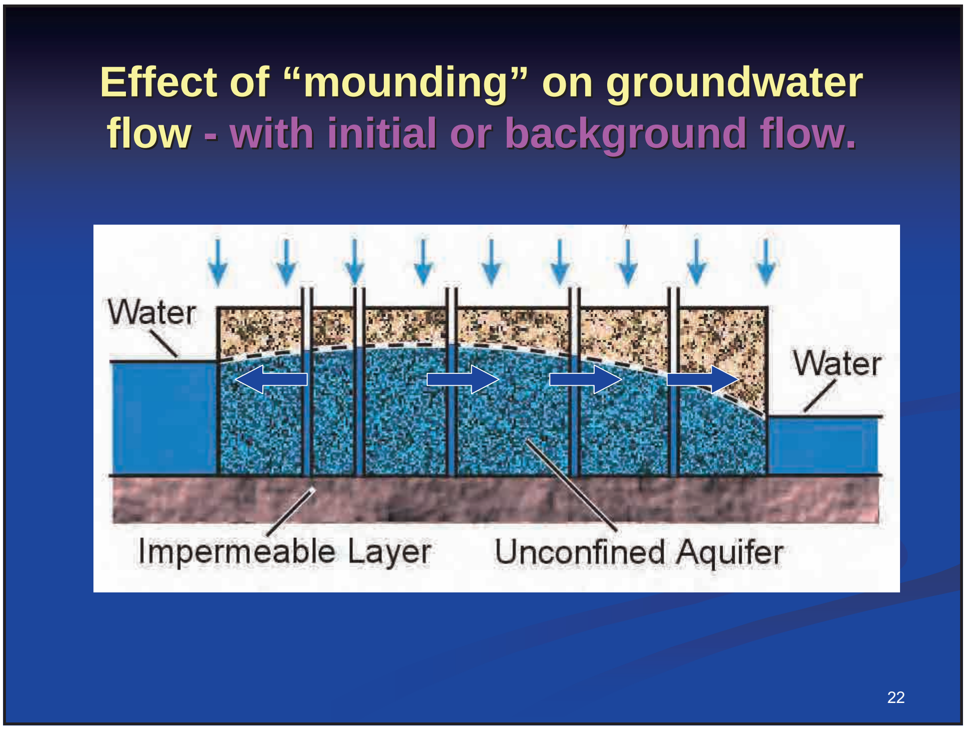


Effect of "mounding" on groundwater flow.

20

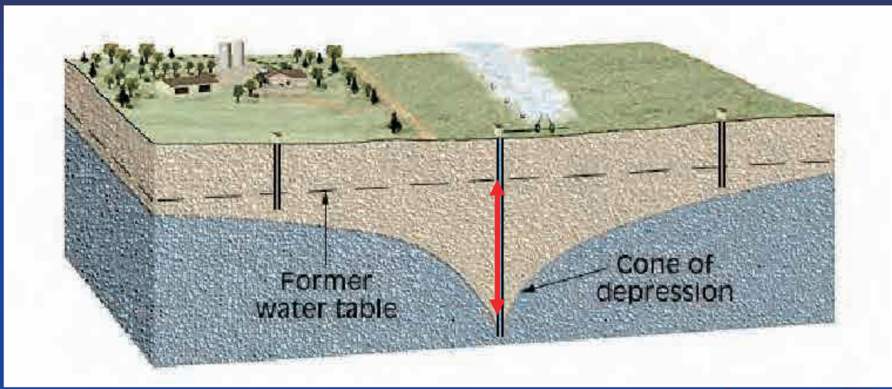
WS-6 ： 地下水シミュレーション





WS-6 ： 地下水シミュレーション

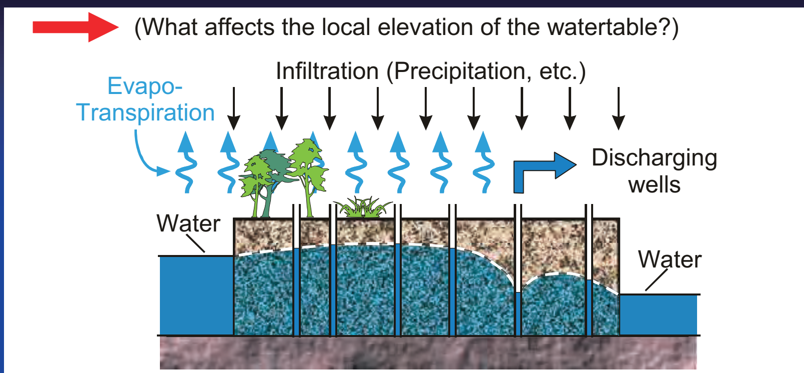
Drawdown



Drawdown = (Static Water Level before Pumping)
- (Dynamic Water Level during Pumping)

23

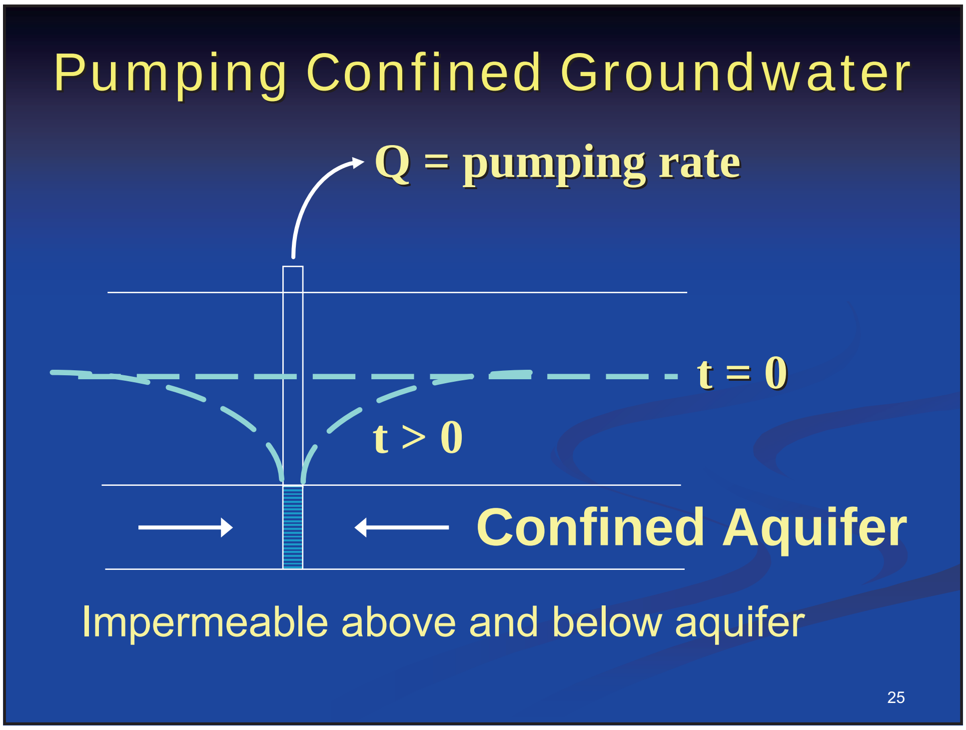
The Water Budget for an Unconfined Aquifer

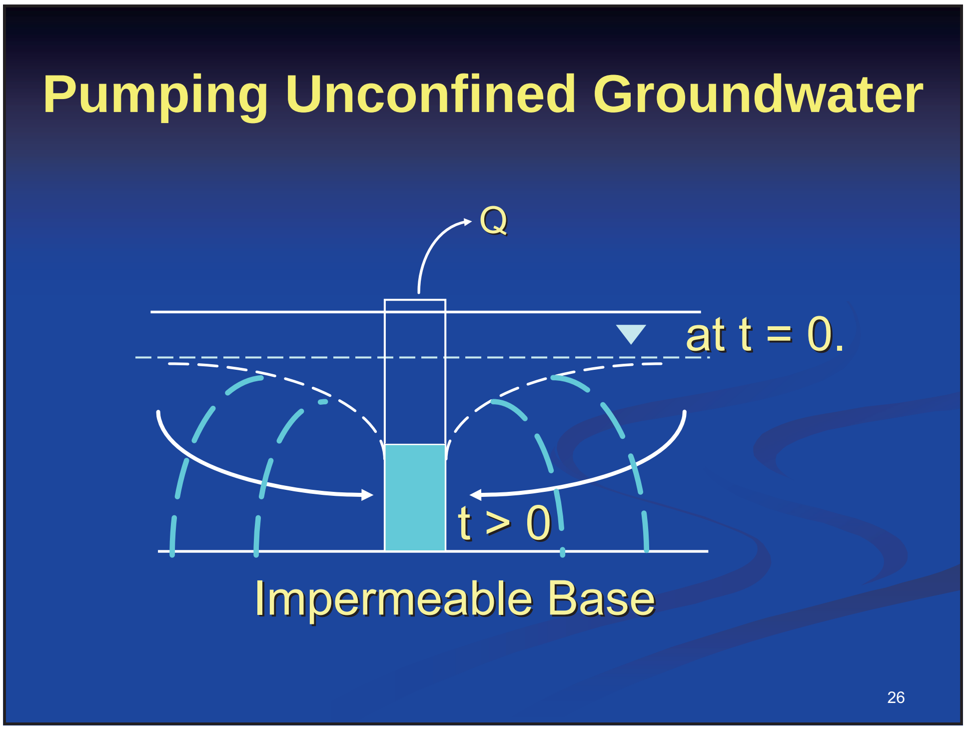


Local groundwater elevations in wells are a function of the following:

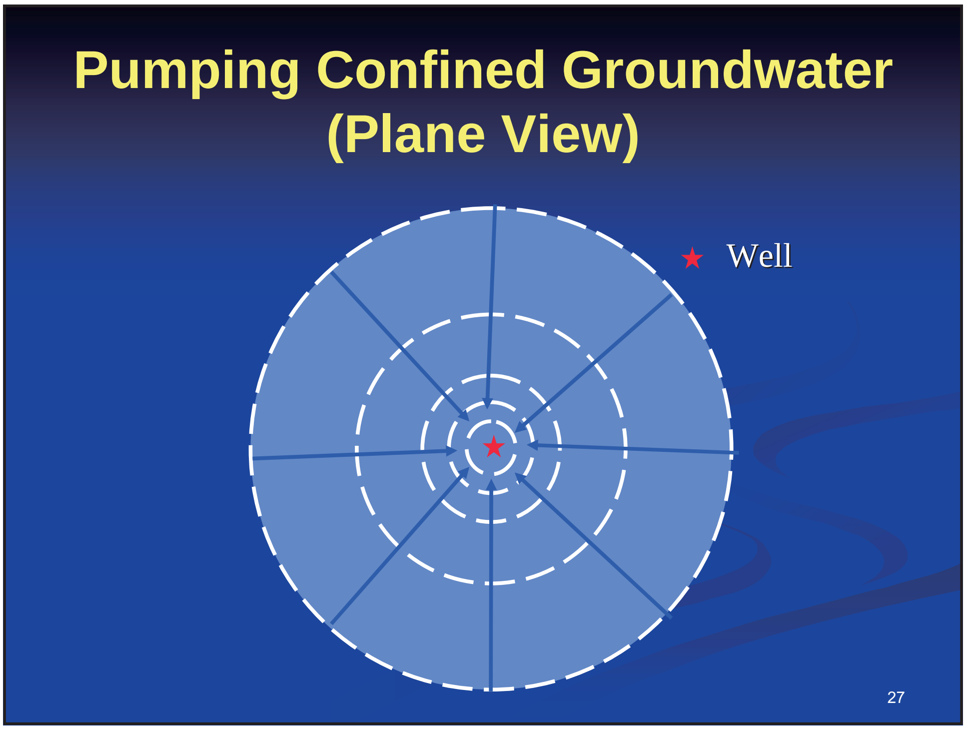
Whether confined or unconfined aquifer;
Differences in the static head of various “sources;
Partitioning of precipitation among infiltration, surface runoff and evapotranspiration (vegetation);
Local production of water from wells;
Hydraulic conductivity or transmissivity.

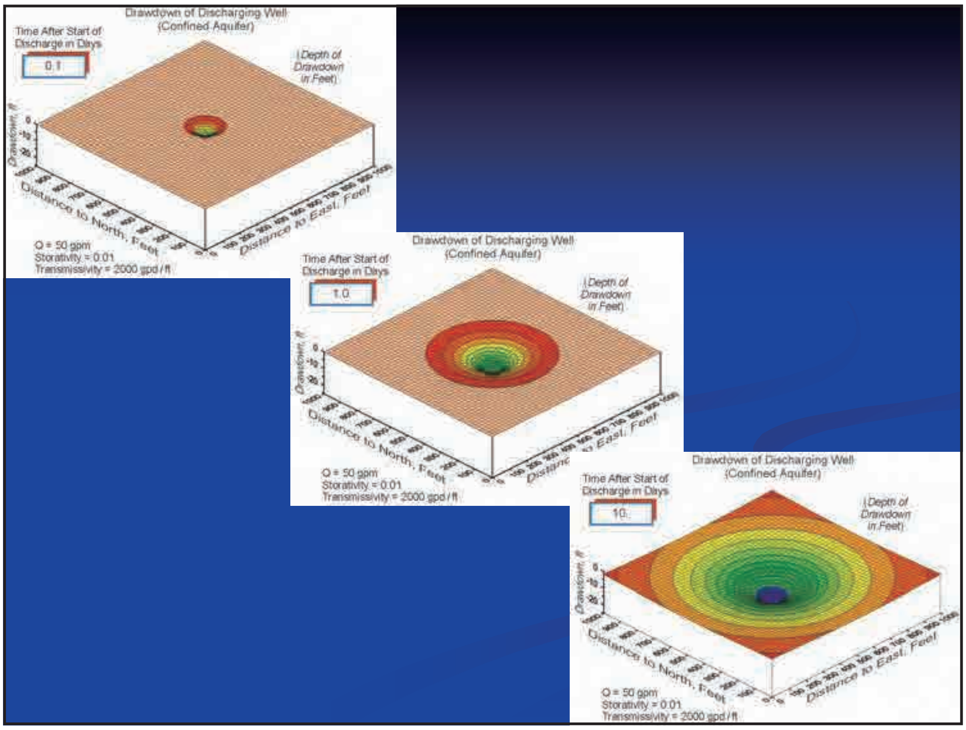
24


Pumping Confined Groundwater
Q = pumping rate
t = 0
t > 0
Confined Aquifer
Impermeable above and below aquifer
25


Pumping Unconfined Groundwater
Q
at t = 0.
t > 0
Impermeable Base
26

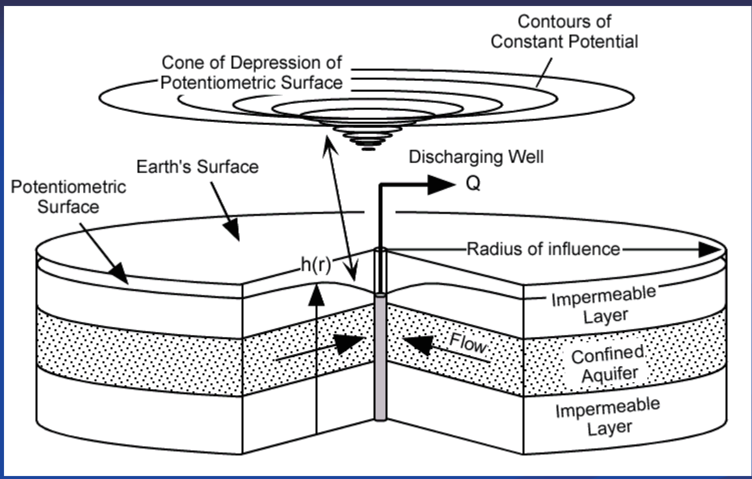
WS-6 ： 地下水シミュレーション





WS-6：地下水シミュレーション

Details on the Geometry of Drawdown and the "Cone of Depression".



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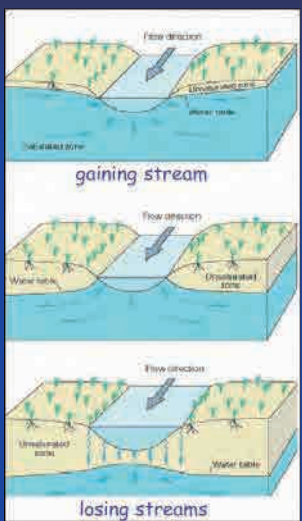
Discharge to and from Stream

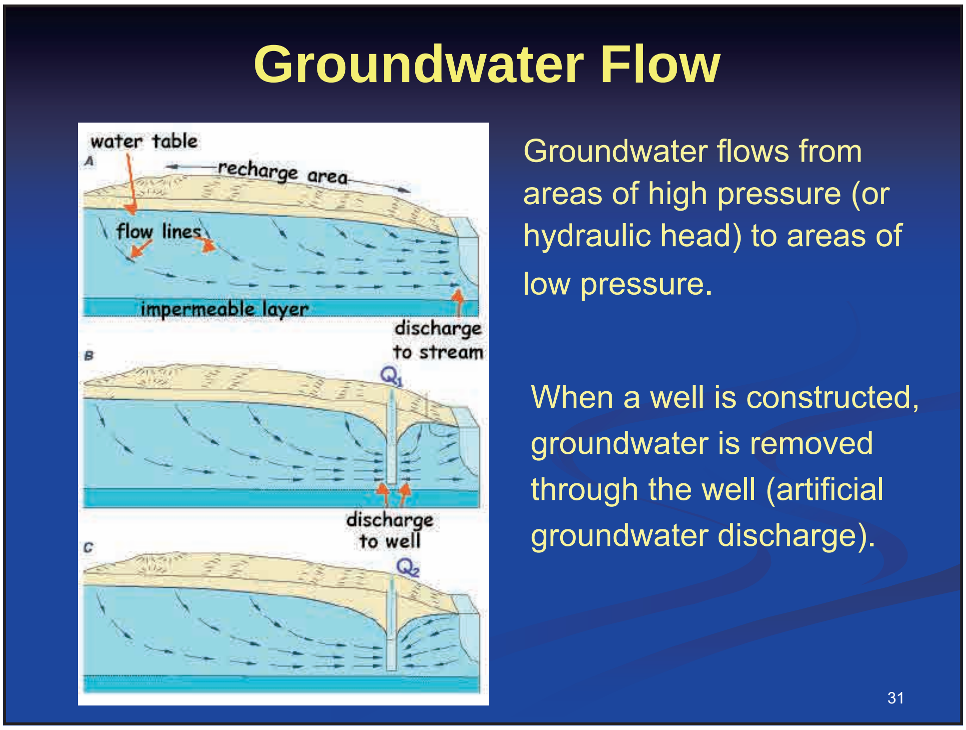


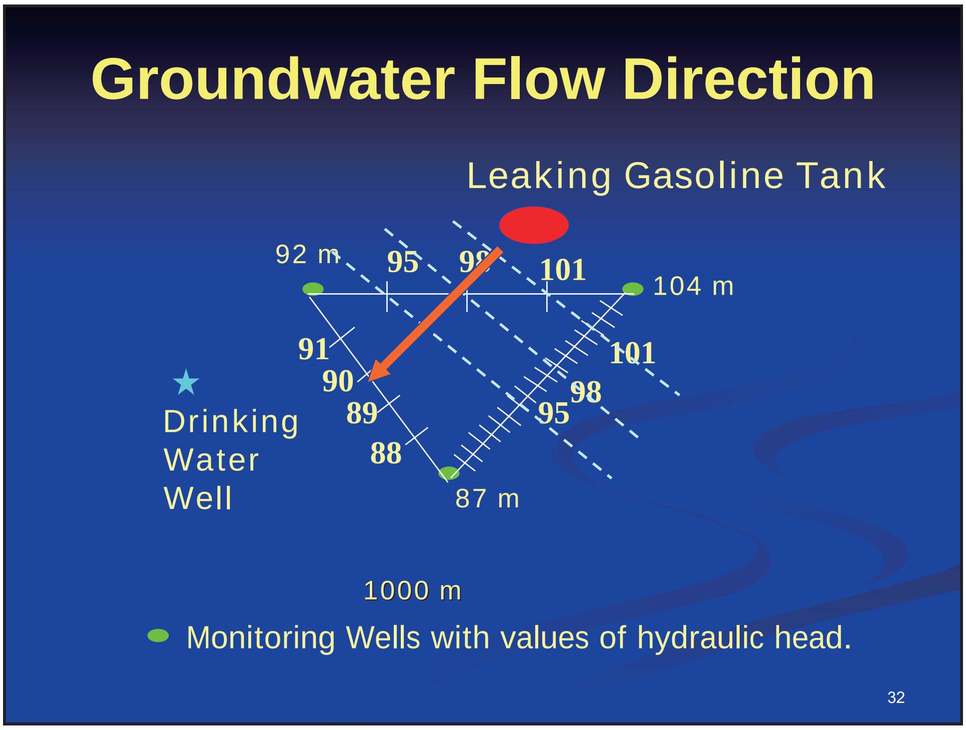
Groundwater discharges to Stream.

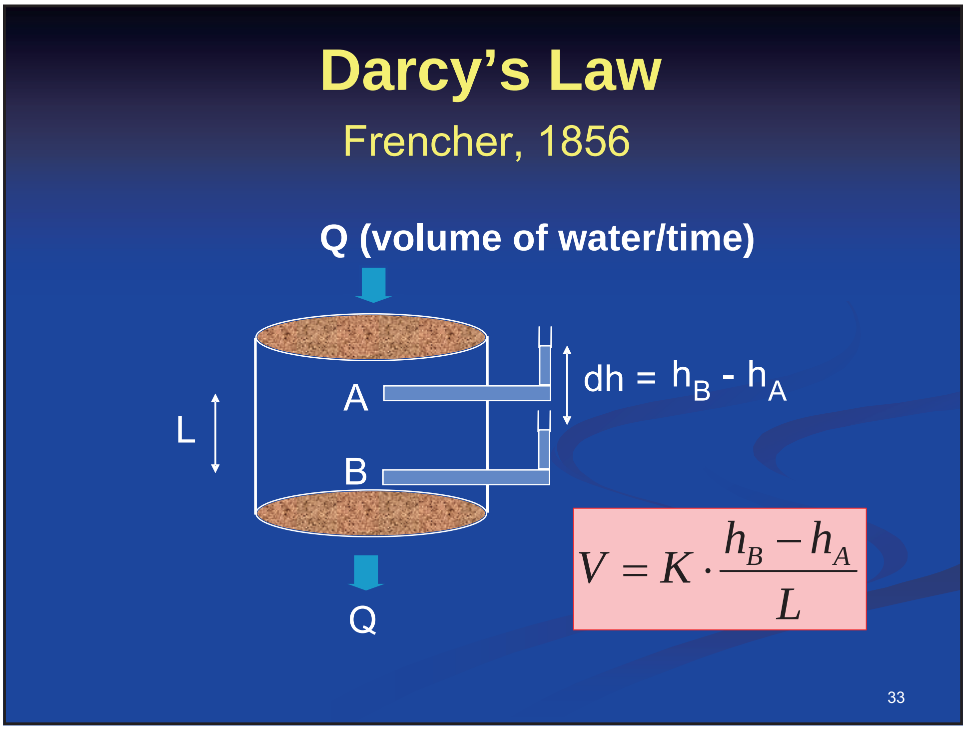
Stream Water discharges to Groundwater.

Groundwater Recharge from Stream

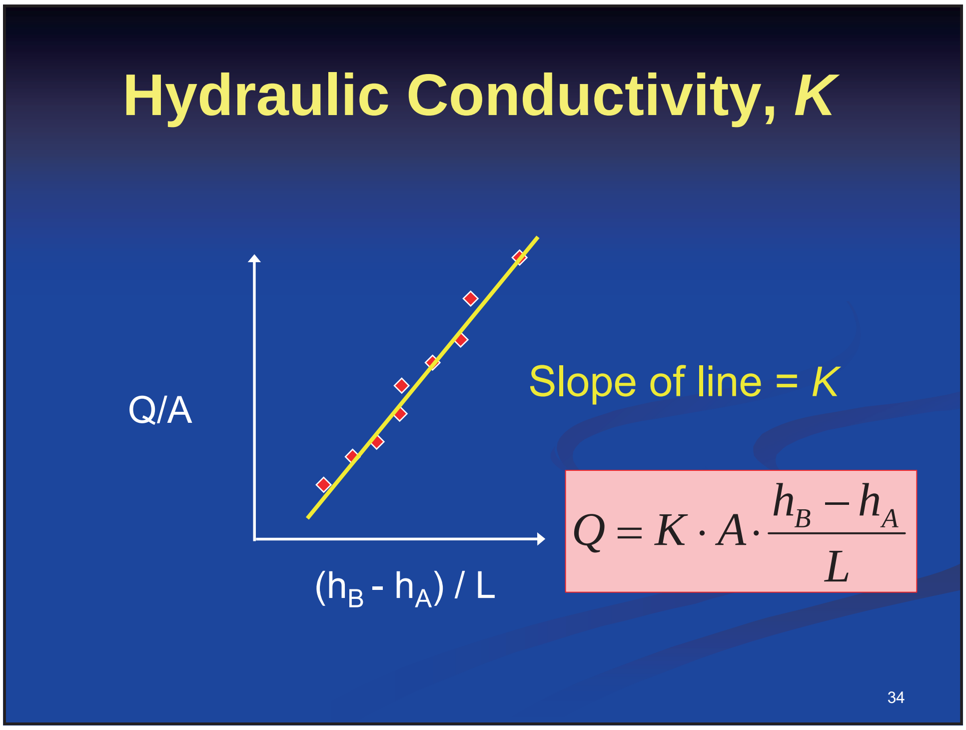
30


Groundwater Flow
water table
A
recharge area
flow lines
impermeable layer
discharge to stream
B
discharge to well
C
Groundwater flows from areas of high pressure (or hydraulic head) to areas of low pressure.
When a well is constructed, groundwater is removed through the well (artificial groundwater discharge).
31


Groundwater Flow Direction
Leaking Gasoline Tank
92 m
95
98
101
104 m
91
90
89
88
87 m
101
98
95
Drinking Water Well
1000 m
Monitoring Wells with values of hydraulic head.
32

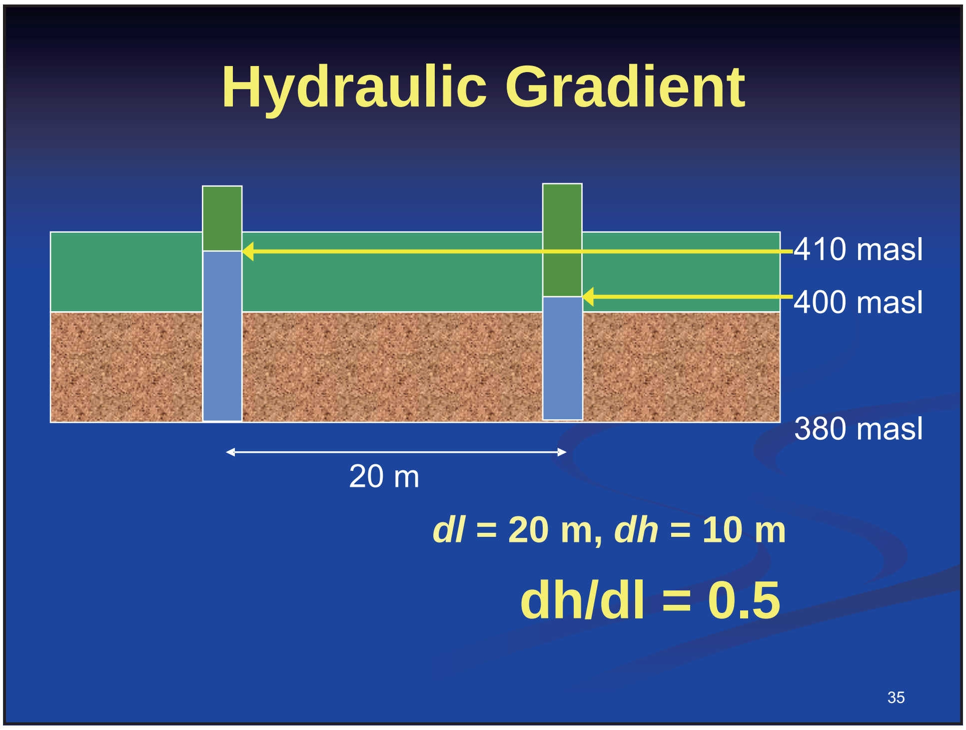


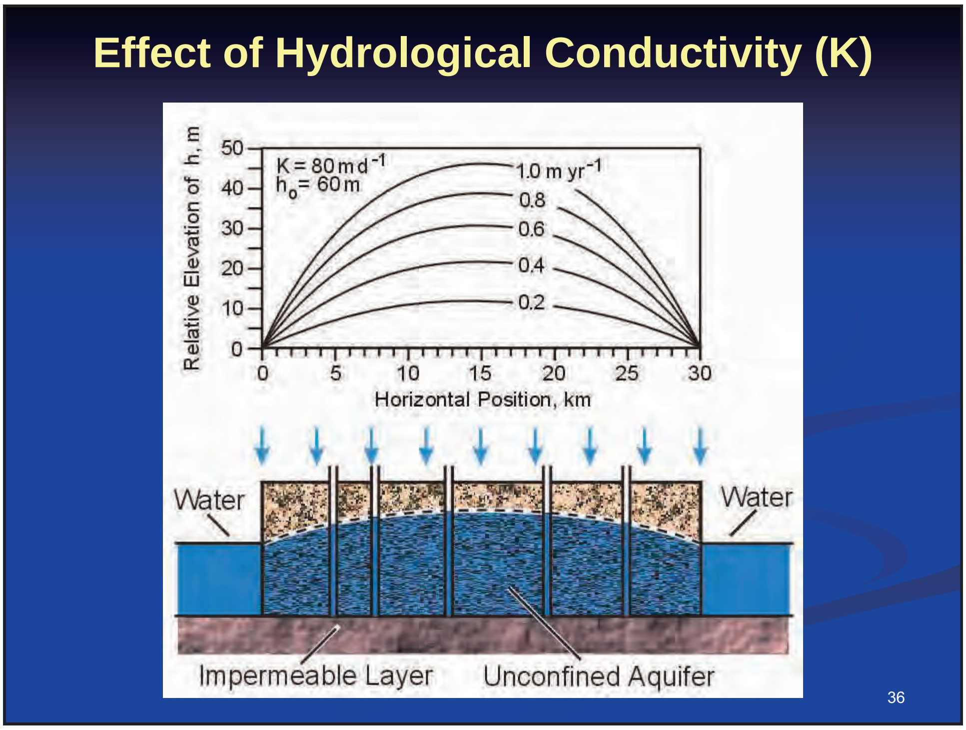
$$V = K \cdot \frac{h_B - h_A}{L}$$



$$Q = K \cdot A \cdot \frac{h_B - h_A}{L}$$

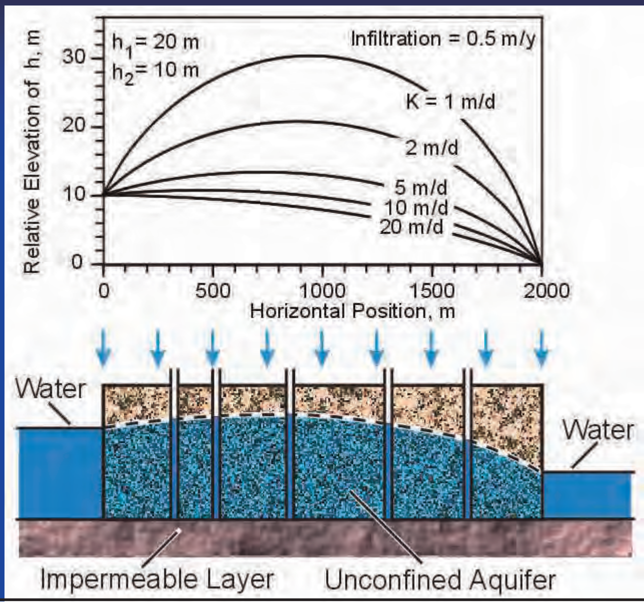
WS-6 : 地下水シミュレーション





WS-6 : 地下水シミュレーション

Effect of Hydrological Conductivity (K)



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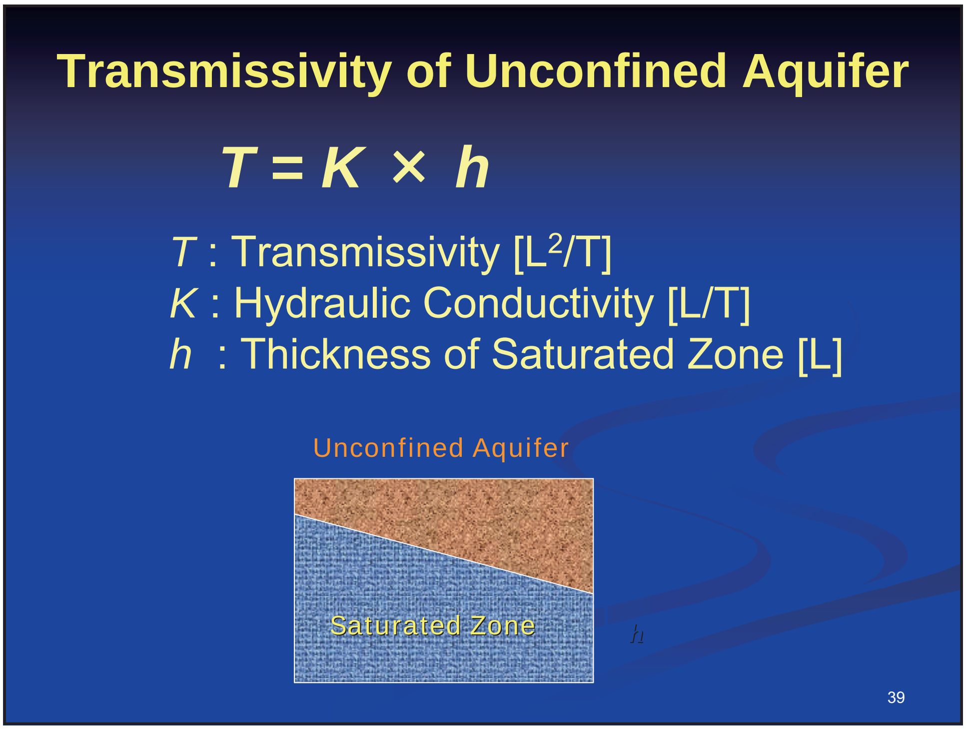
Transmissivity of Confined Aquifer

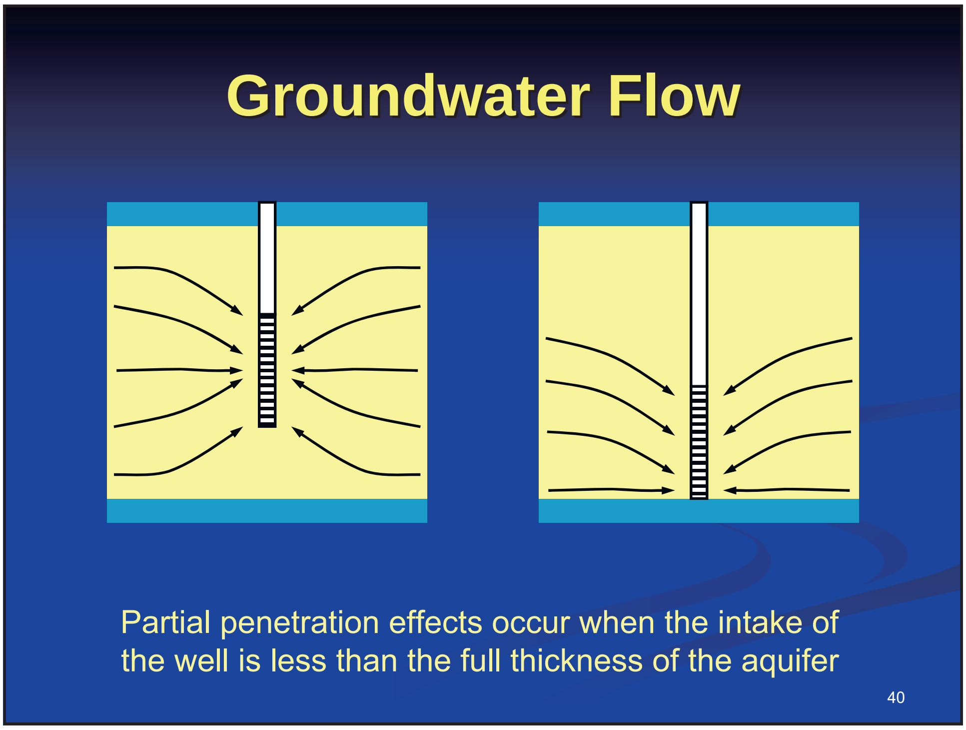
$$T = K \times b$$

T : Transmissivity [L^2/T]
K : Hydraulic Conductivity [L/T]
b : Thickness of Aquifer [L]

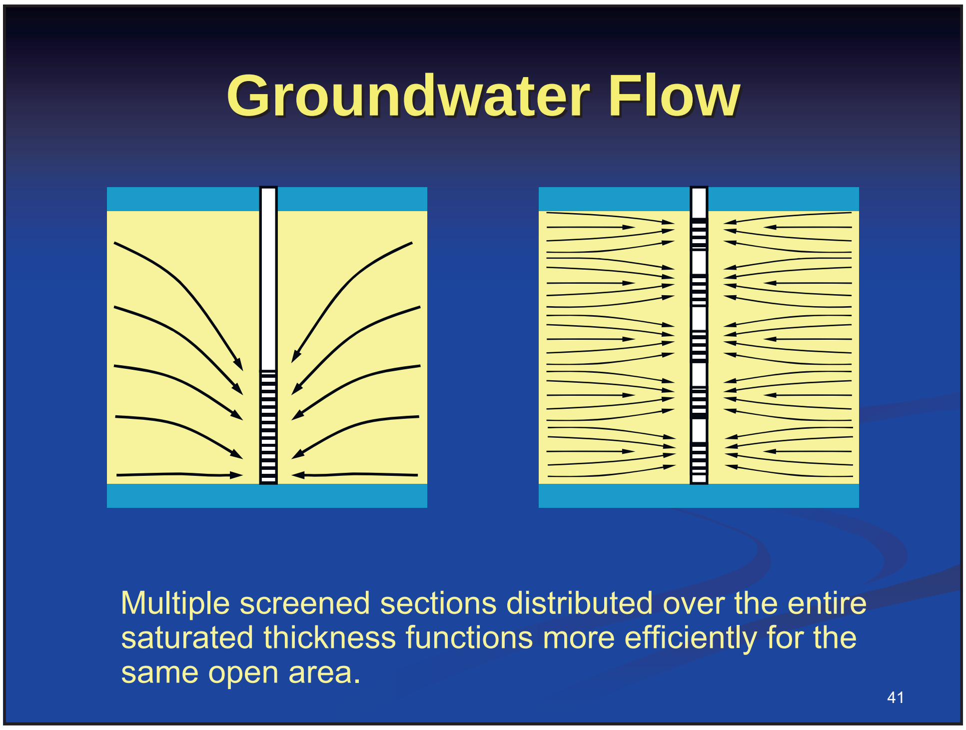
$$T = K \times b$$
$$= 10\ \text{m/d} \times 10\ \text{m}$$
$$= 100\ \text{m}^2\text{/day}$$

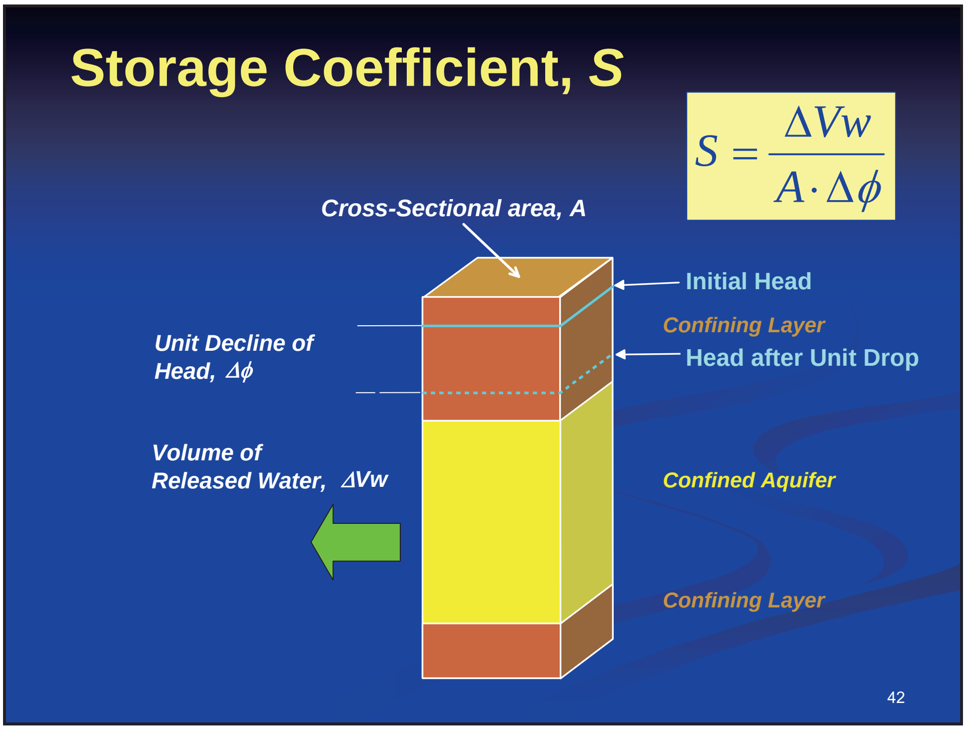
38

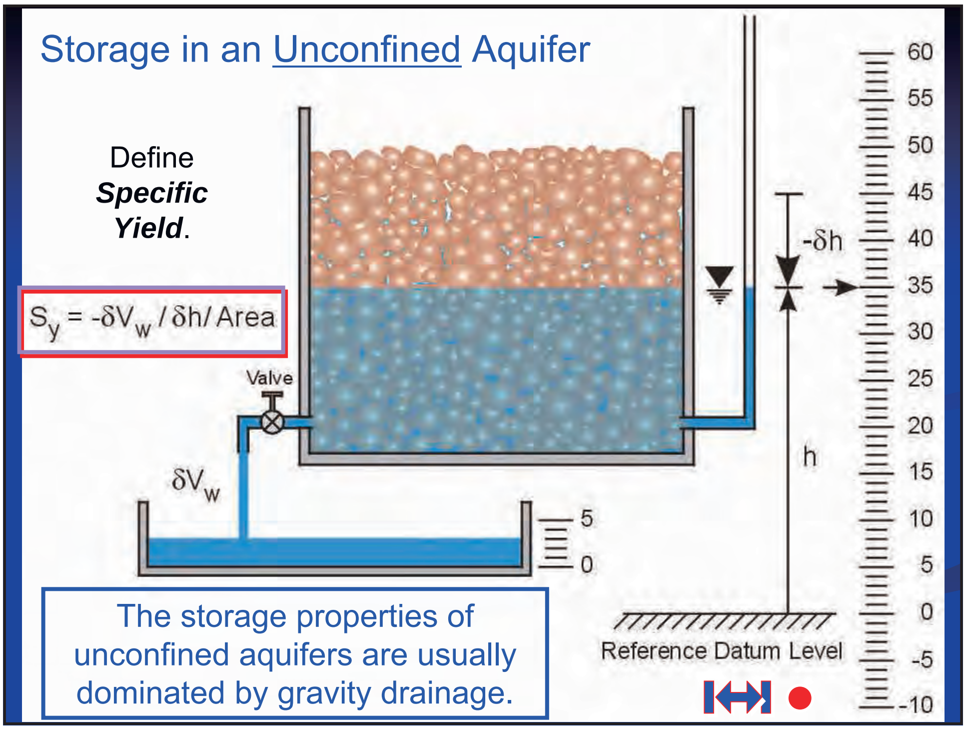

Transmissivity of Unconfined Aquifer
T = K × h
T : Transmissivity [L2/T]
K : Hydraulic Conductivity [L/T]
h : Thickness of Saturated Zone [L]
Unconfined Aquifer
Saturated Zone
h
39


Groundwater Flow
Partial penetration effects occur when the intake of the well is less than the full thickness of the aquifer
40

WS-6 : 地下水シミュレーション







Groundwater Balance Equation

$$R(t) - D(t) = \frac{dS}{dt}$$

R(t): Recharge to a Groundwater Basin for a period

D(t): Discharge from the Groundwater Basin for the period

dS/dt: Storage change in the Groundwater Basin for the period

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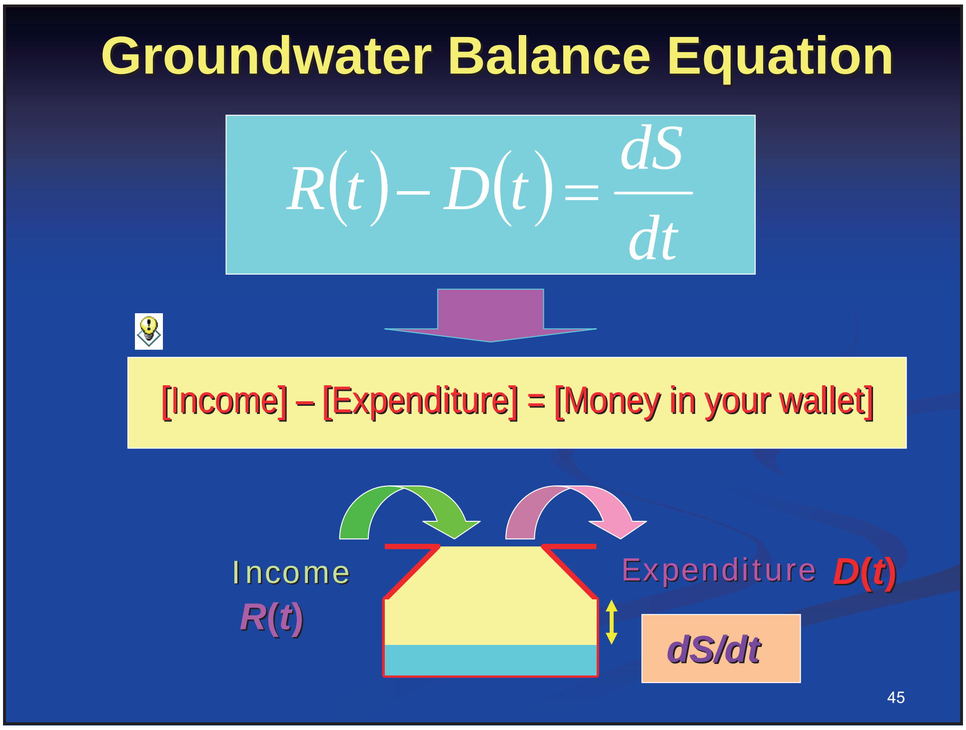
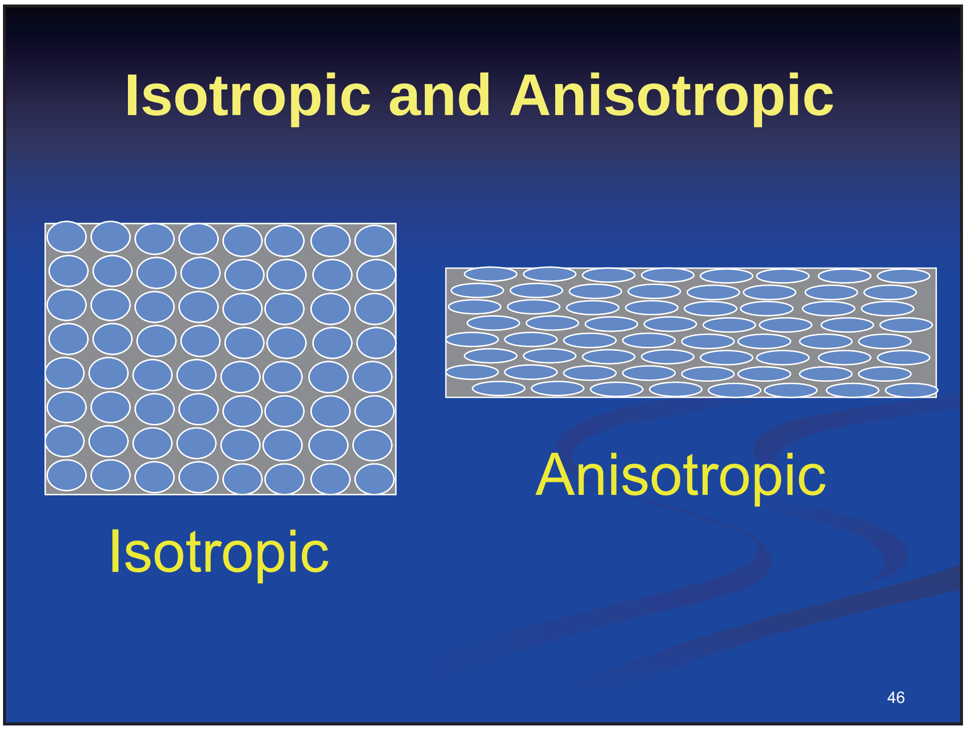
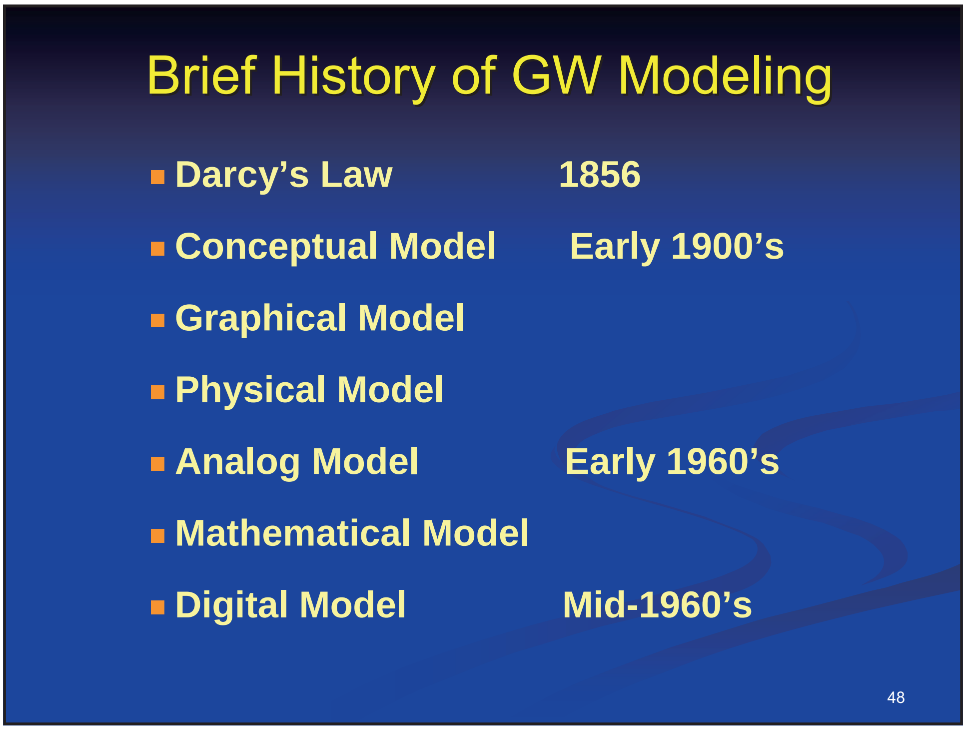
WS-6 ： 地下水シミュレーション

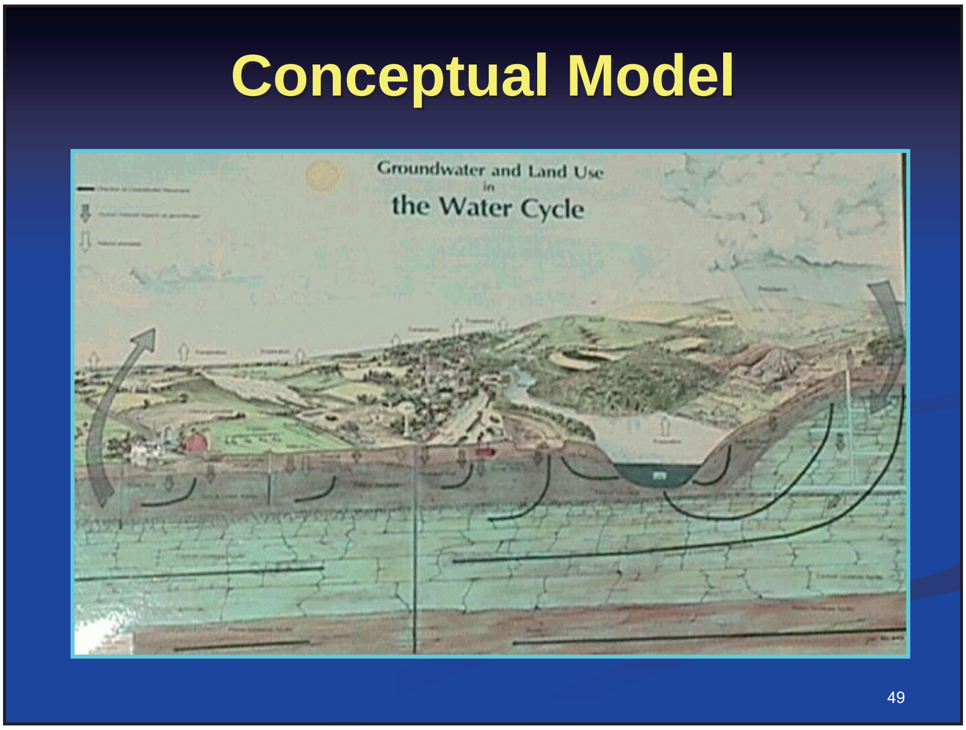


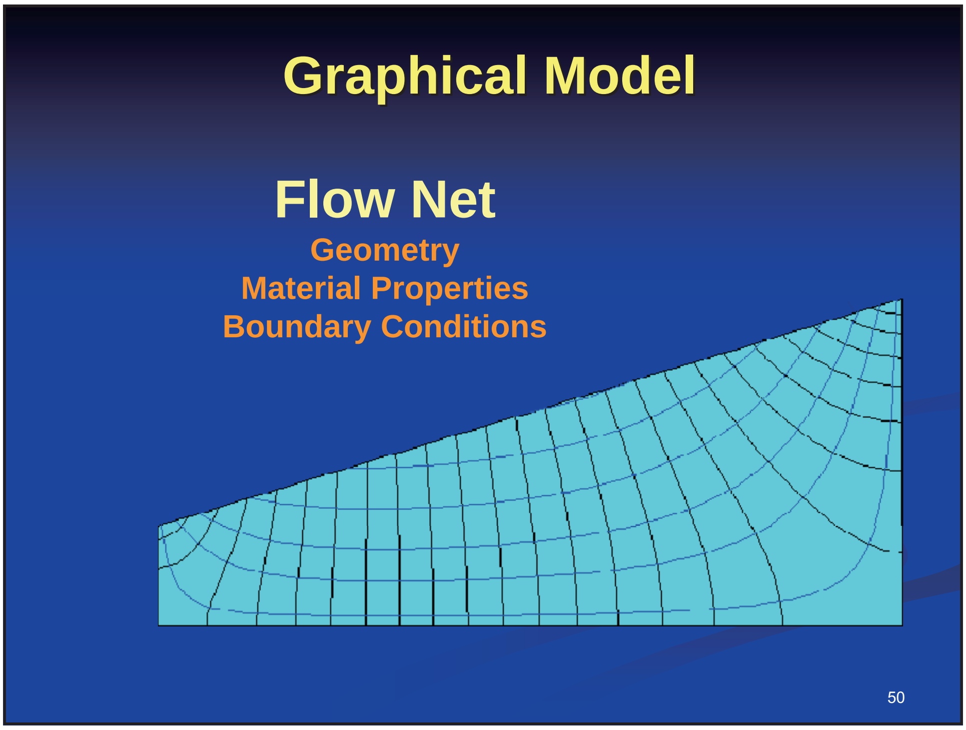


WS-6 ： 地下水シミュレーション



WS-6 ： 地下水シミュレーション

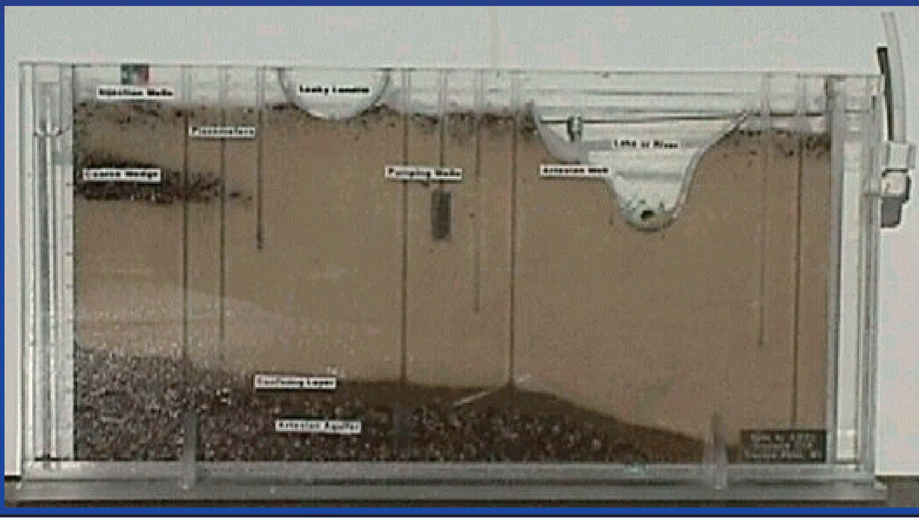




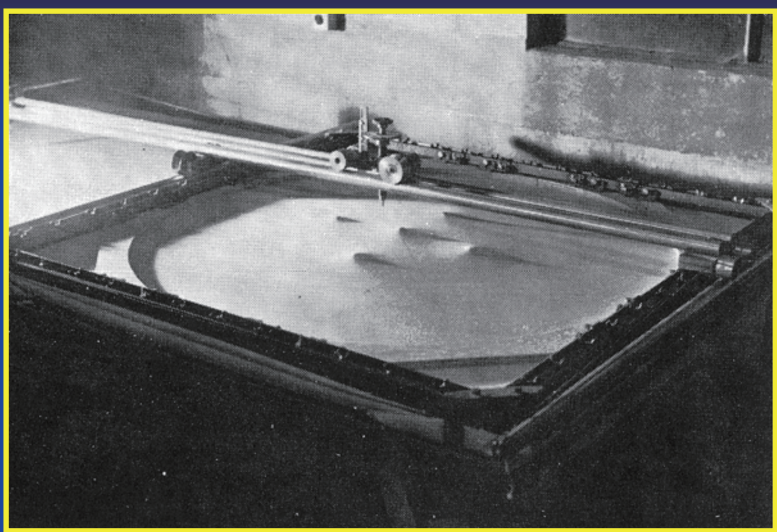
WS-6 ： 地下水シミュレーション

Physical Model

Sand Tank



Analog Model (Rub Sheet Model)



Source：D.K.Todd「Groundwater Hydrology, 2nd」（Wiley,1980)

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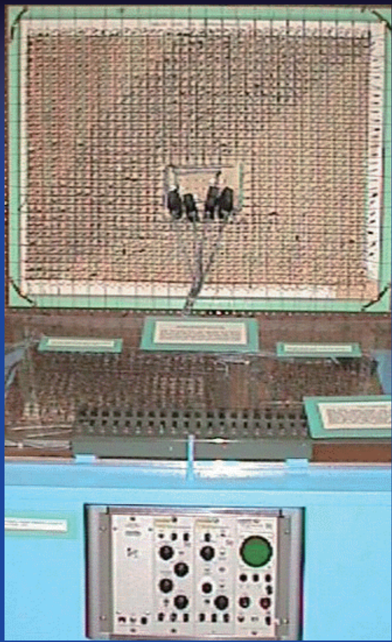
Analog Model



Electrical Analog Model

Ohm's Law

V = RI

Darcy's law

V = KI

The model was prepared for Champaign-Urbana Illinois Area (circa 1960).

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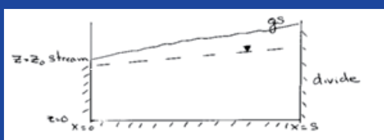
Mathematical Model

Analytical Solution

Toth (1962) developed a solution for Steady State flow in a 2-D section from a stream to a divide



he solved the Laplace Equation

$$\frac{\partial^2 h}{\partial x^2} - \frac{\partial^2 h}{\partial z^2} = 0$$

boundaries

left $\frac{\partial h}{\partial x}(0,z)=0$ right $\frac{\partial h}{\partial x}(s,z)=0$

lower $\frac{\partial h}{\partial z}(x,0)=0$

upper water table $\mathrm{h}(x,z_o)=z_o+cx=z_o+\tan(\alpha)x$

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Result of Toth (1962) solution

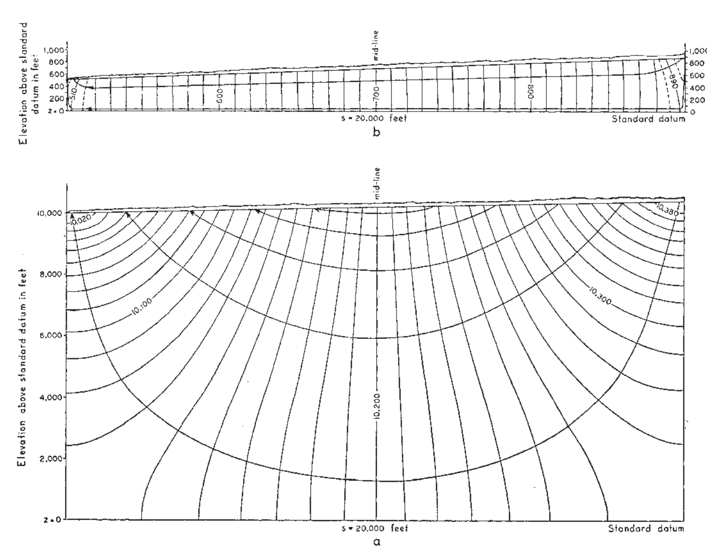

Fig. 3. Two-dimensional theoretical potential distributions and flow patterns for different depths to the horizontal impermeable boundary.

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History of Digital Computer Model

The First Numerical Simulation Model was prepared by

Tyson and Weber (1964)

The model was applied to the study of groundwater basin under the coastal plain near Los Angeles, California.

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Tyson and Weber (1964) Model

A horizontal two-dimensional groundwater flow model, which used the finite-difference method.

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right)-Q=S\frac{\partial h}{\partial t}$$

T : Transmissivity,
S : Storage coefficient,
Q : Net external inflow,
h : Head,
t : Time.

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Themes for Groundwater Flow Theory

- **Limitation of Darcy Law's application**
  - Depends on the flow velocity
  - Critical point or range between laminar flow and turbulent flow
  - Effect of adsorptivity of soil grains
- **Mechanism of groundwater flow in fissure aquifer and Karst aquifer**
- **Parameters about substance transport**

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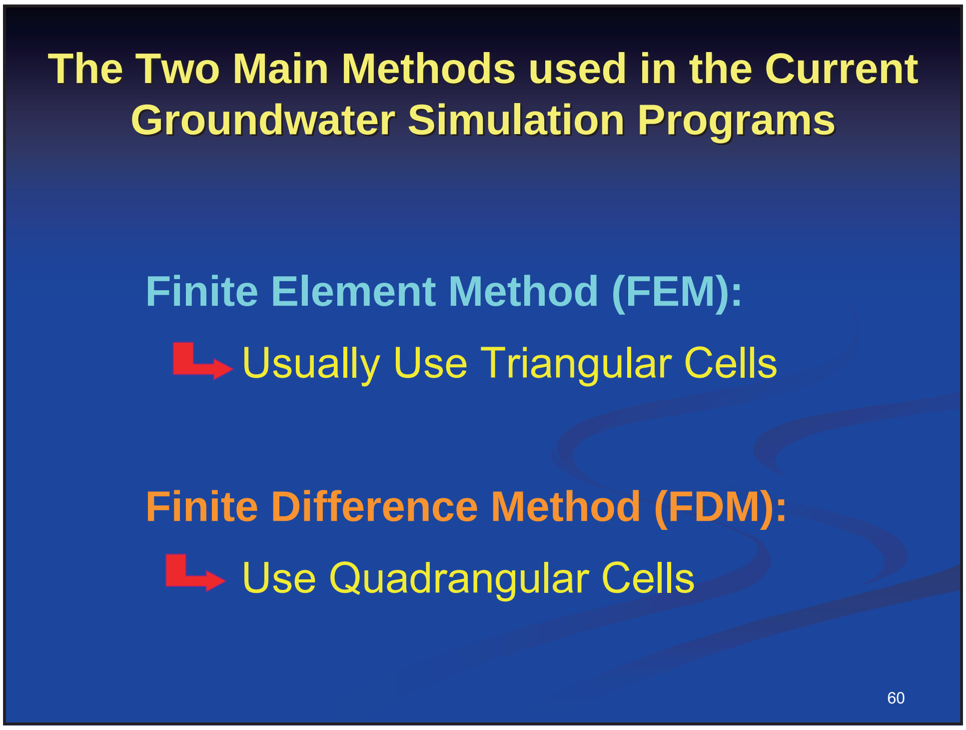
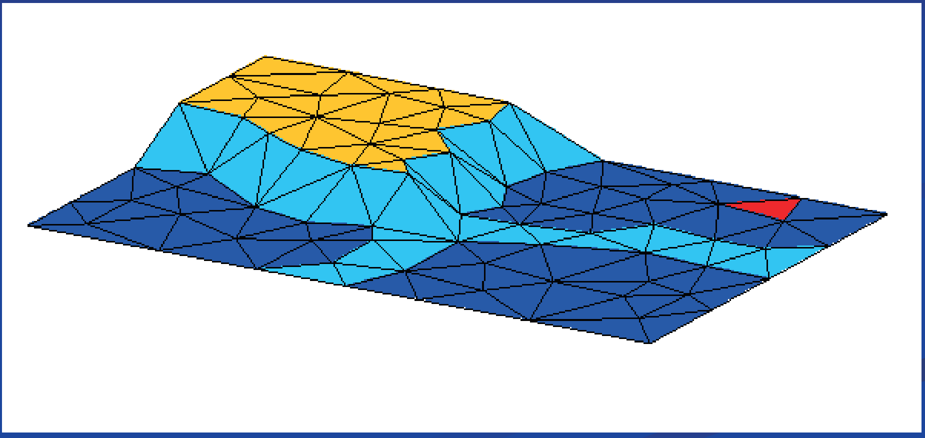
WS-6 ： 地下水シミュレーション



An Example of FEM Grid



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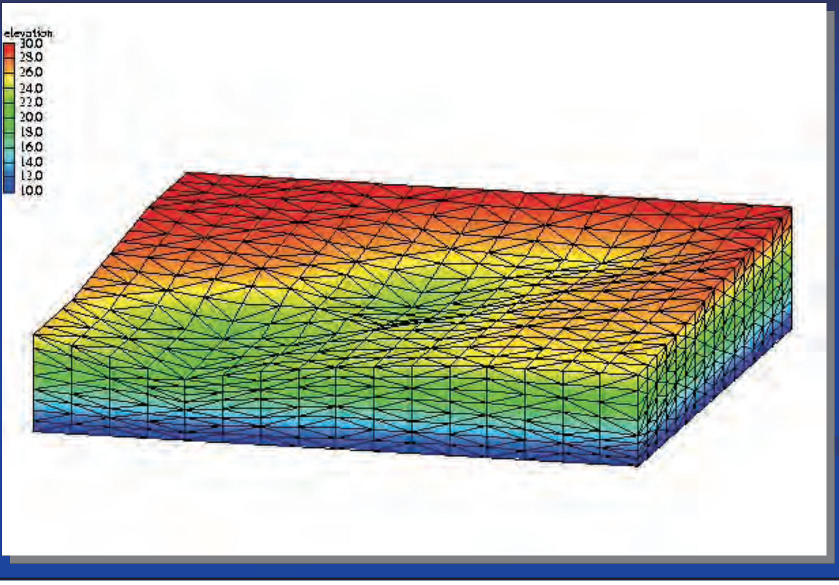
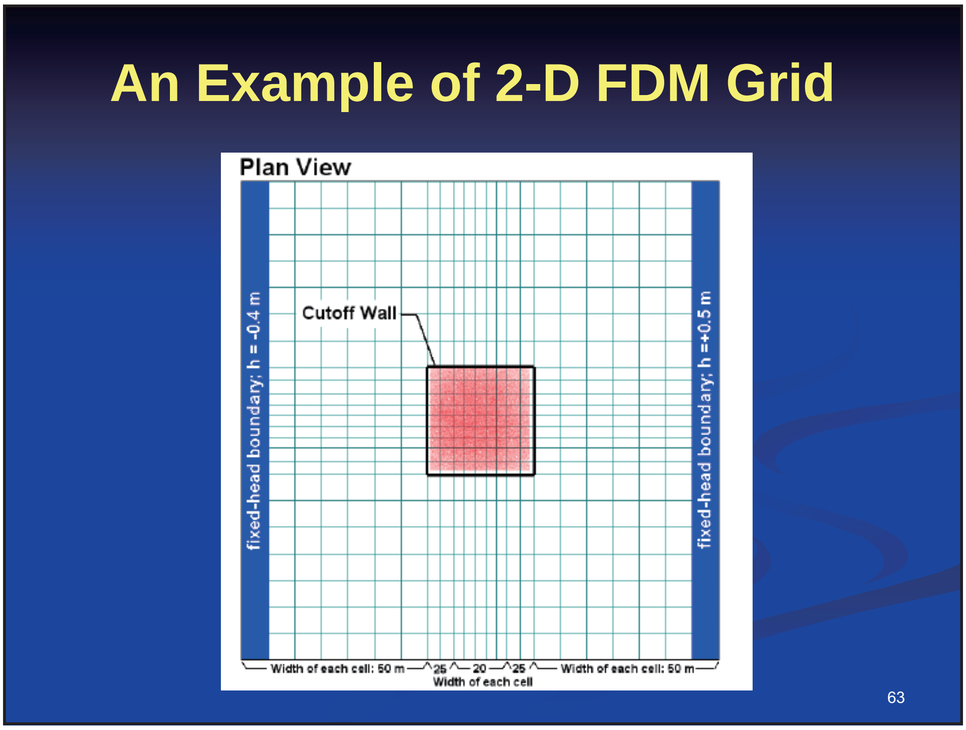
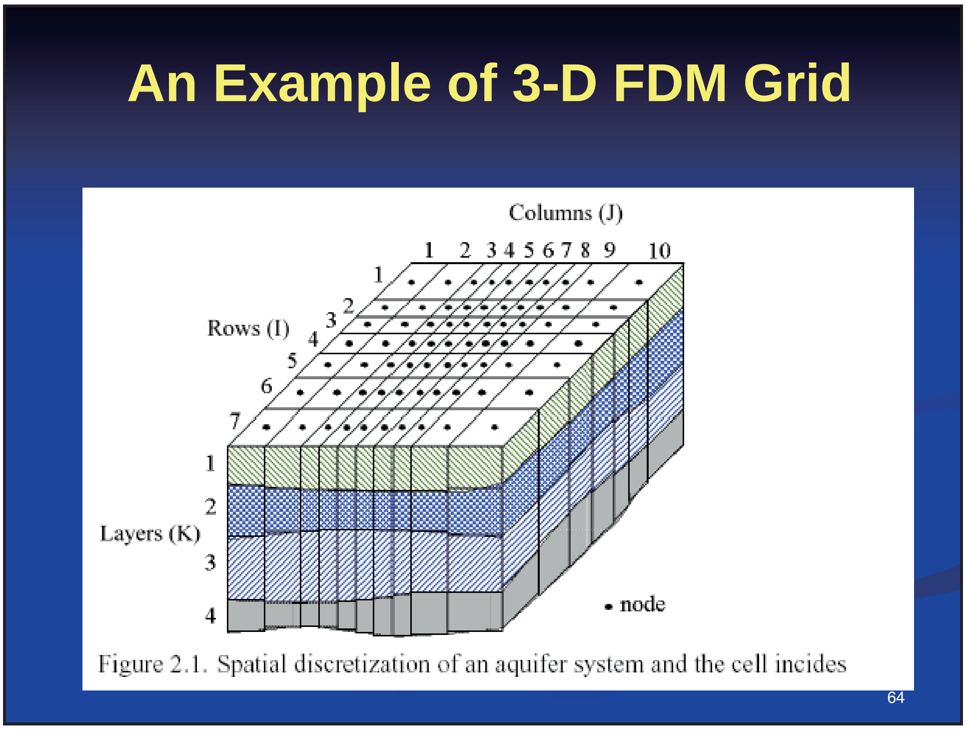
An Example of 3-D FEM Grid




An Example of 2-D FDM Grid
Plan View
Cutoff Wall
fixed-head boundary; h = -0.4 m
fixed-head boundary; h =+0.5 m
Width of each cell: 50 m
25
20
25
Width of each cell: 50 m
Width of each cell
63


An Example of 3-D FDM Grid
Columns (J)
1 2 3 4 5 6 7 8 9 10
Rows (I)
1 2 3 4 5 6 7
Layers (K)
1 2 3 4
• node
Figure 2.1. Spatial discretization of an aquifer system and the cell incides
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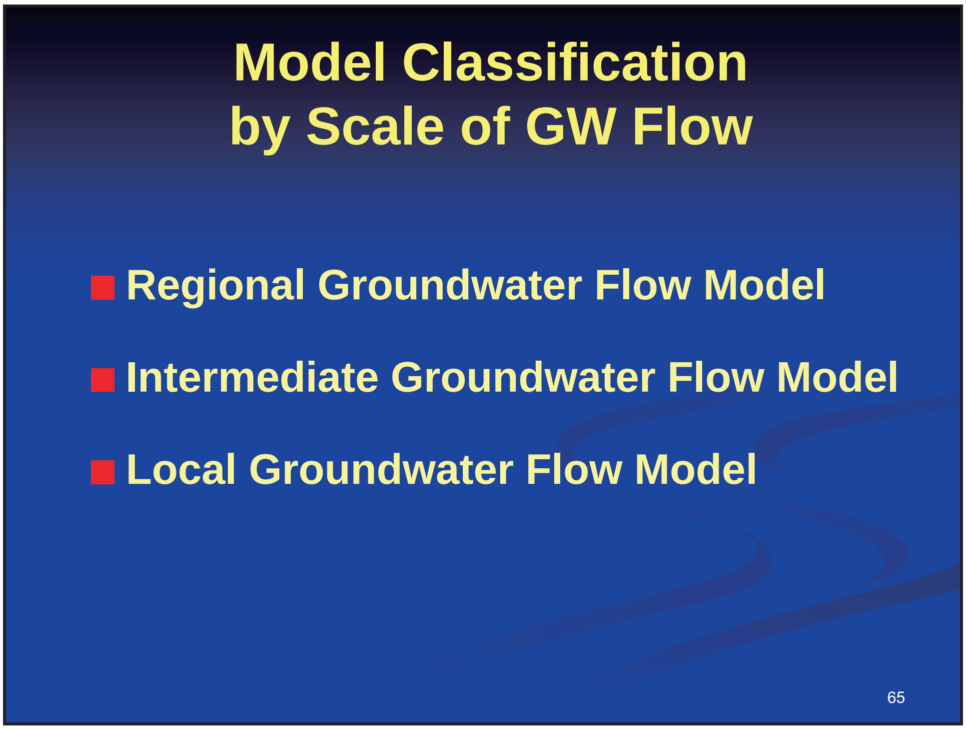
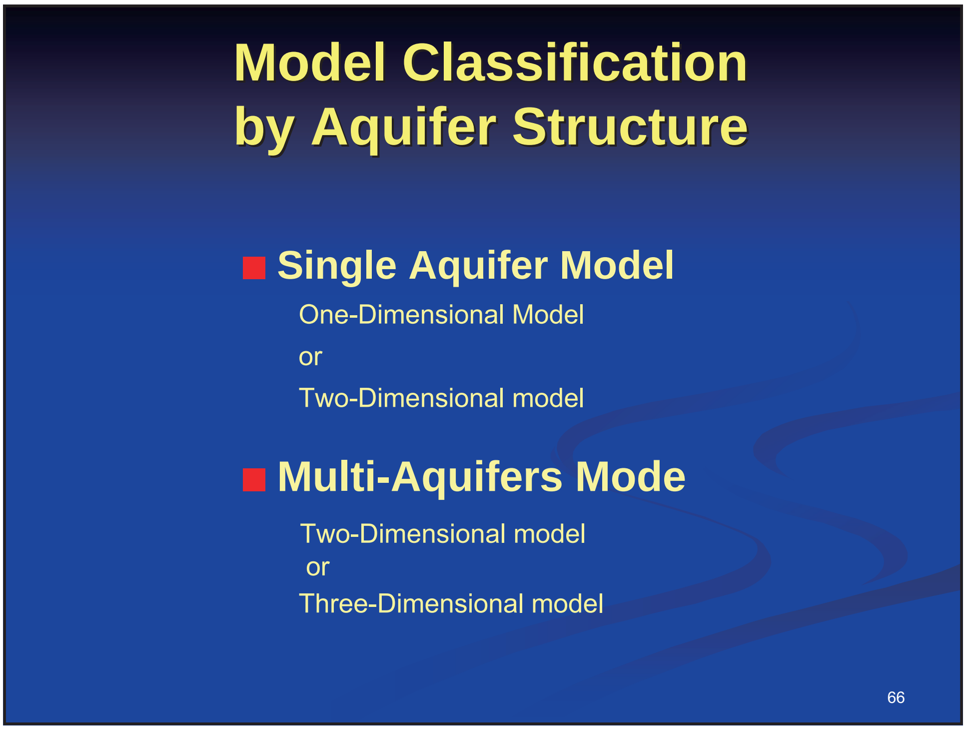
WS-6 : 地下水シミュレーション





WS-6 ： 地下水シミュレーション

Model Classification by Model Structure

- One-Dimensional (1-D) Vertical Model
- Two-Dimensional (2-D) Plane Model
- Two-Dimensional (2-D) Vertical Model
- Quasi Three-Dimensional (Q3-D) Model
- Three-Dimensional (3-D) Model

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How Many Programs Can We Use

http://www.scisoftware.com/html/products.html

Page1

- 3DFATMIC - 3-D Subsurface Flow and Transport Model
- 3DFEMFAT - 3-D Flow and Transport Model through Saturated-Unsaturated Media
- AQUA3D - 3-D Groundwater Flow and Contaminant Transport Model
- AquiferTest for Windows - Pumping Test and Slug Test Analysis
- Aquifer Test Toolbox - Excel Workbooks for Aquifer Test Data
- AquiferWin32 - Pump Test and Slug Test Analysis Software
- AQUIPACK - Aquifer Properties and Contaminant Transport Analysis
- AT123D - Analytical Groundwater Transport Model for Long-Term Pollutant
- BIOF&T 2-D/3-D - Biodegradation, Flow and Transport in the Saturated/Unsaturated Zones
- BIO1d - 1-D model which simulates biodegradation and sorption in contaminant transport
- Chemflo - Simulates Water and Chemical Movement in Unsaturated Soils

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How Many Models Can We Use

http://www.scisoftware.com/html/products.html

Page2

- FEFLOW - Finite Element Subsurface Flow System
- ChemFlux - Finite Element Mass Transport Model
- FLONET/TRANS - FLONET/TRANS 2-D cross-sectional groundwater flow and transport
- FLOWPATH II - 2-D Groundwater Flow, Remediation, and Wellhead Protection Model
- GFLOW 2000 - Conjunctive Surface Water and Groundwater Flow
- GMS - Groundwater Modeling System - Sophisticated Groundwater Modeling
- Groundwater Vistas - Advanced Model Design and Analysis for MODFLOW, MODPATH, MT3D, and so on.
- Kinetic/Equilibrium Reactions in Saturated-Unsaturated Media Model

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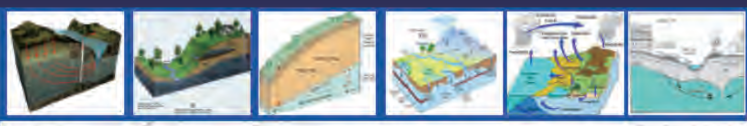
Example of HP of a Commercial Software Site



Software

3DFATMIC	3DFATMIC - 3D microbe and chemical flow and transport model for computing and predicting the distribution of pressure head, moisture content, flow velocity, and total head
3DFEMFAT	3DFEMFAT is a 3-Dimensional Finite-Element Model of Flow And Transport through Saturated-Unsaturated Media, including coupled density-dependent flow and transport.
AQUA3D	AQUA3D - AQUA3D solves transient groundwater flow with anisotropic flow conditions. Solves transient transport of contaminants and heat with convection, decay, adsorption and velocity-dependent dispersion.
Argus ONE	Argus Open Numerical Environments (Argus ONE) - A finite-element and finite-difference numerical preprocessor providing a unified modeling solution for groundwater models
BIOF&T	BIOF&T - BIOF&T models biodegradation, flow and transport in the sat/unsat zones in 2 or 3 dimensions in heterogeneous, anisotropic porous media or fractured media
Bioslurp	BIOSLURP is an areal finite-element model to simulate three-phase (water, oil and gas) flow and multicomponent transport in ground water in the unsaturated zone gas phase.
ChemFlux	ChemFlux is a contaminant transport software modeling package for modeling of mass transport, contaminant concentrations and plume migration.
FEFLOW	FEFLOW Model - 2D/3D finite element subsurface flow system - model for density-dependent groundwater flow, heat flow and contaminant transport
GMS - Groundwater Modeling System	GMS supports both finite-difference and finite-element groundwater models in 2D and 3D including MODFLOW 2000, MODPATH, MT3DMS/RT3D, SEAM3D, ART3D, UTCHEM, FEMWATER, PEST, UCODE, MODAEM and SEEP2D.

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Example of HP of a Free Software WEB Site

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Famous Software for Groundwater Simulation

- **PMwin (Processing MODFLOW)**
  Integrated simulation system for modeling groundwater flow and transport processes
- **Visual MODFLOW**
  The most easy-to-use modeling environment
- **GMS (Groundwater Modeling System)**
  The newest and most comprehensive groundwater modeling software available
- **FEFLOW**
  Different from the above three programs by using FEM but not Modflow

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About MODFLOW

- Most famous, but is not perfect.
- Very difficult to be modified
- Five times renewed. The newest version (Modflow 2005)
- Source code is free released by USGS
  ttp://water.usgs.gov/nrp/gwsoftware/modflow.html
- Difficult to be compiled, so be used for many commercial software.

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Free Released Groundwater and Hydrological Software from USGS


USGS
science for a changing world

MODFLOW and Related Programs

MODFLOW: 3D Finite-Difference Groundwater Flow Model

Status of MODFLOW Versions and MODFLOW-Related Programs Available on USGS Web Pages (January, 2011)
MODFLOW-2005 Version: 1.8 (Dec. 18, 2009)
MODFLOW-LGR Version: 1.2 (May 18, 2010)
MODFLOW-NWT Version: 1.0 (May 11, 2011)
(MODFLOW-2000 can be found under the banner "Legacy and Superseded Software")

Related Programs for Simulation of Hydrologic Processes, Model Calibration, and Groundwater Management

CFP Version 1.8 Feb 23, 2011
Conduit Flow Process for MODFLOW 2005

GSFLOW Version: 1.1.3 (March 1, 2011)
Coupled Groundwater and Surface-water FLOW model based on the USGS Precipitation-Runoff Modeling System (PRMS) and Modular Groundwater Flow Model (MODFLOW-2005

GWM-2000 Version 1.1.3 [Dec. 7, 2009] and GWM-2005 Version 1.3.0 [March 9, 2011]
Capability for groundwater management using optimization techniques with either MODFLOW-2000 or MODFLOW-2005

MF2K-FMP (Win) Version 1.00, (May 19, 2006) and MF2005-FMP2 (Win) Version 1.0.00, (Oct. 28, 2009)
Estimate dynamically integrated supply-and-demand components of irrigated agriculture as part of the simulation of surface-water and groundwater flow

MF2K-GWT Version 1.9.8 and MOC3D Version 3.52, (Oct. 22, 2008)

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MODFLOW Equation

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t}$$

Kxx, *Kyy*, and *Kzz* : values of hydraulic conductivity along the *x*, *y*, and *z* coordinate axis, which are assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1});

h : the potentiometric head (L);

W : a volumetric flux per unit volume;

Ss : the specific storage of the porous material (L^{-1}); and

t : time (T).

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Recommended Software

PMWIN53

- The first graphical user interfaces for MODFLOW (from 1991).

  The longest history of program development
- Easy to input and modify parameters and factors.
- Kindly error check function and model running record
- High speed of running and excellent stability of model running.

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Recommended Software

PMWIN53

More than all other advantage is that The software is

FREE!!!

You can save as more as over 1,200 US Dollar

77

Recommended Software

PMWIN53

http://www.pmwin.net/pmwin5.htm

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Main Features of PMWIN53

Support Main Relative Programs

- MODFLOW
- MOC3D
- MT3D
- MT3DMS
- UCODE
- PEST
- PMPATH

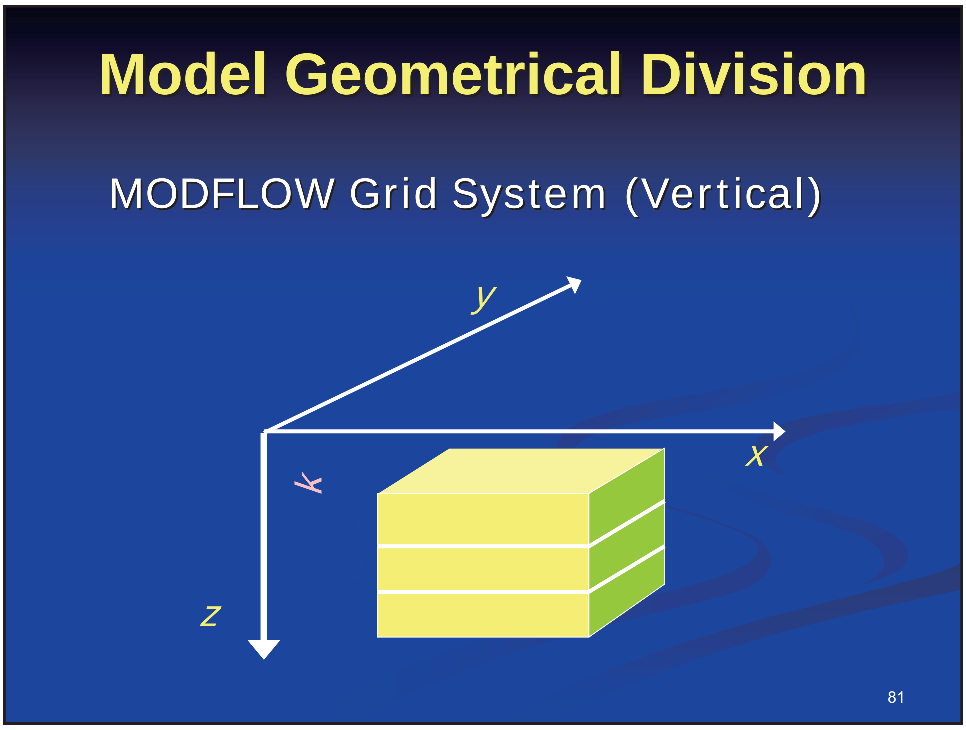
79

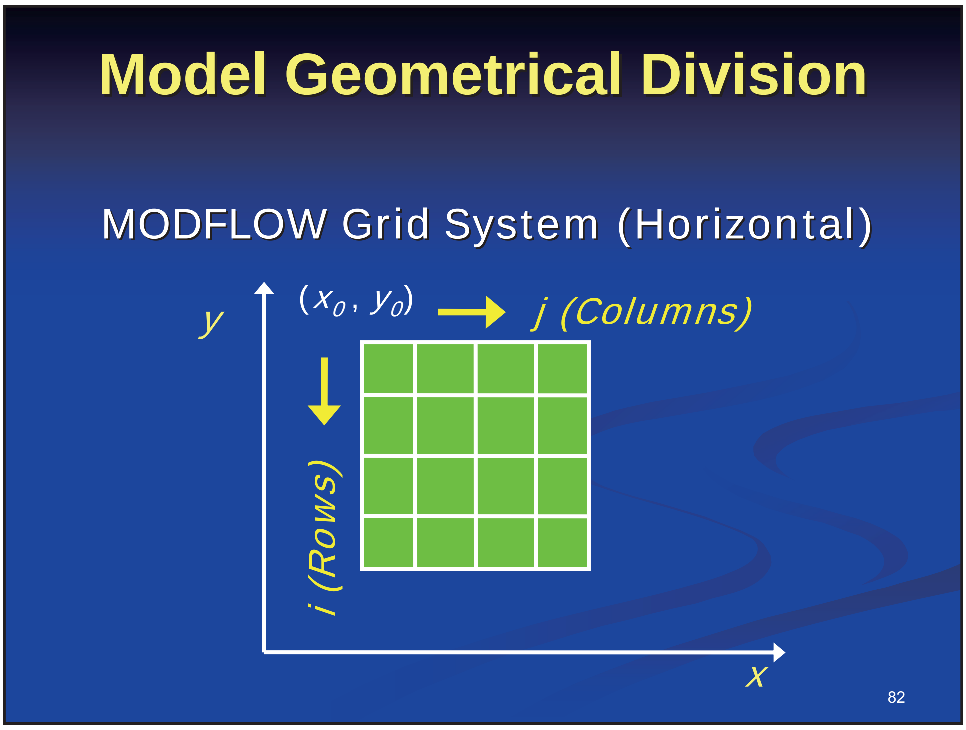
Main Features of PMWIN53

Support Almost all Main Relative Packages

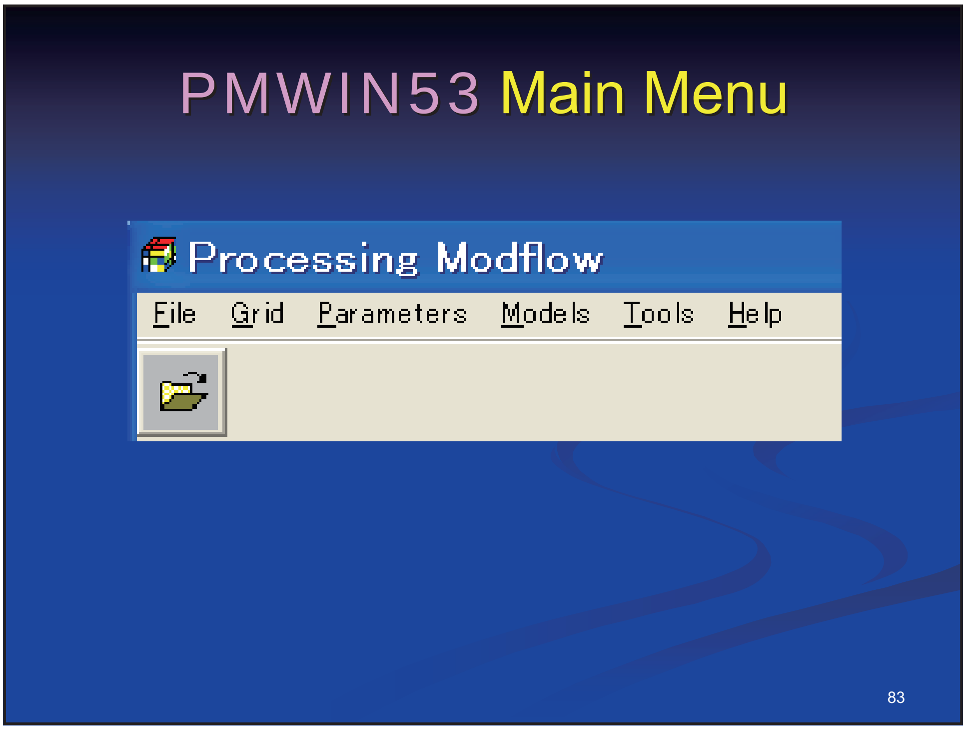
- Density
- Interbed storage
- Evapotranspiration
- Recharge
- Wells
- Wetting capability
- Others

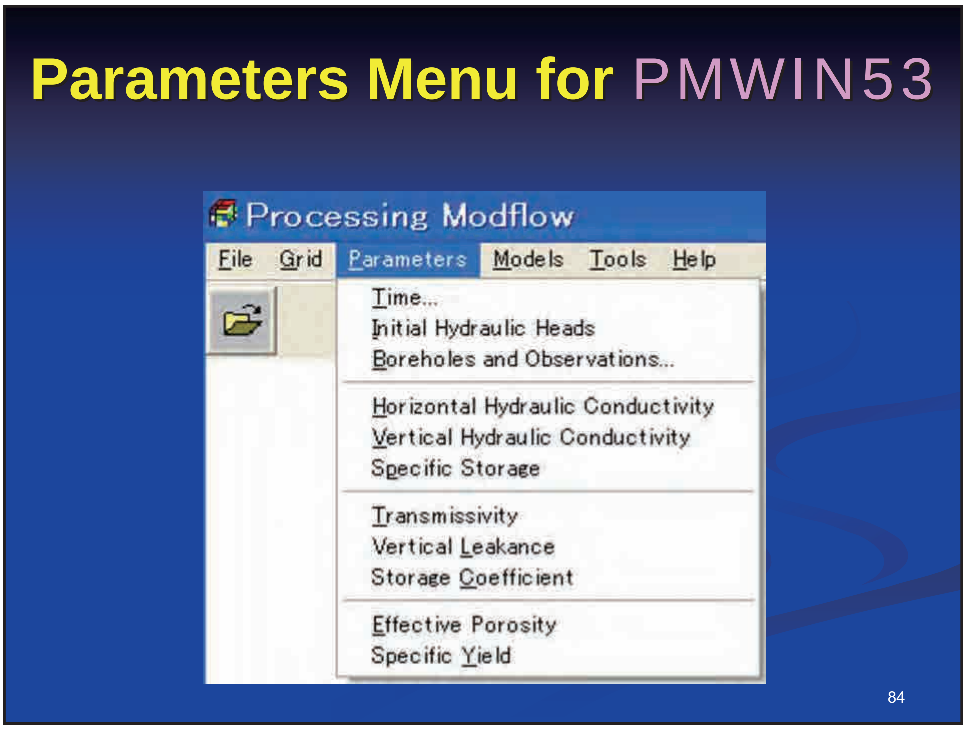
80


Model Geometrical Division
MODFLOW Grid System (Vertical)
y
x
k
z
81

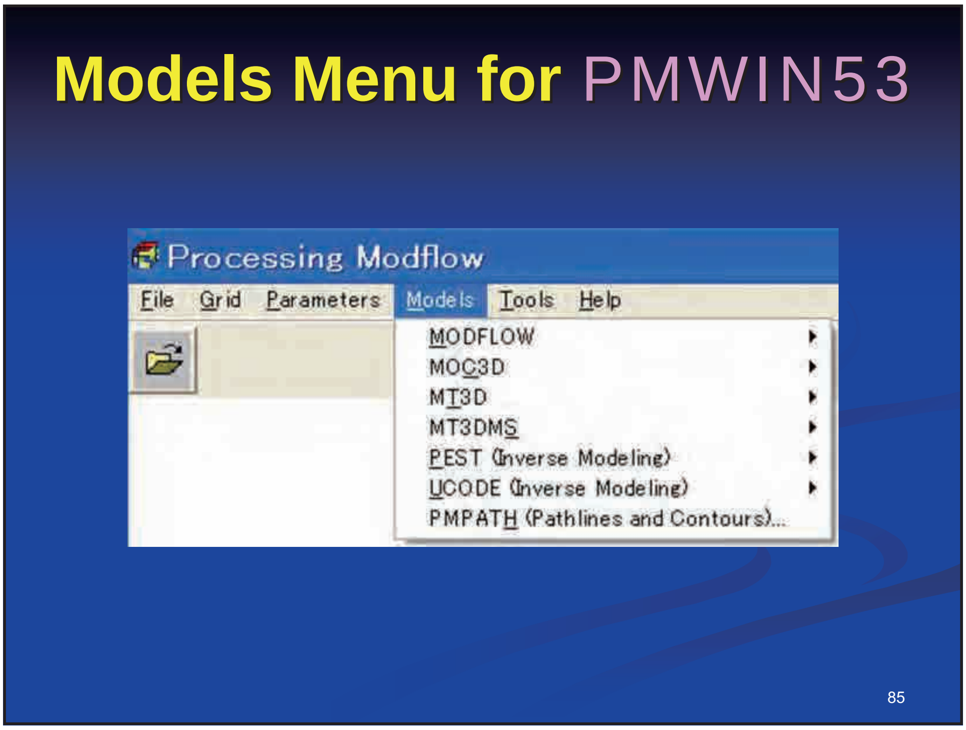

Model Geometrical Division
MODFLOW Grid System (Horizontal)
y
(x0 , y0)
j (Columns)
i (Rows)
x
82

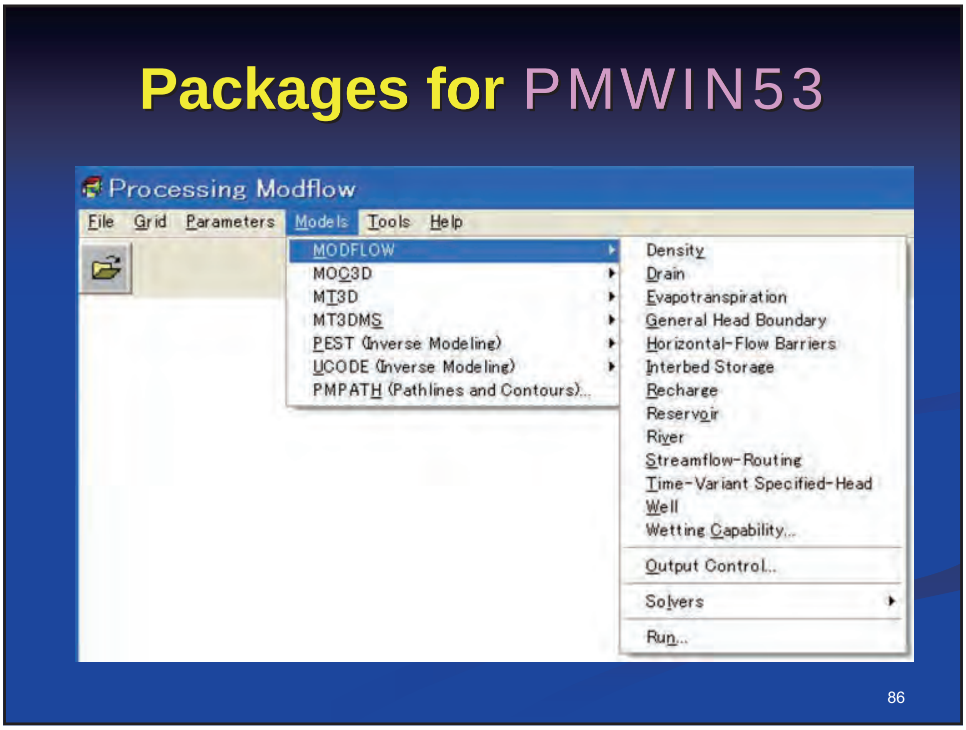
WS-6：地下水シミュレーション





WS-6 ： 地下水シミュレーション





Utility of Groundwater Simulation Model (1) Purpose

- Identification Model
- Prediction Model
- Management Model

87

Utility of Groundwater Simulation Model (2) Simulation Target

- Flow Model
- Land Subsidence Model
- Solute Transport Model
- Density Fluid Model
- Heat Transport Model

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WS-6：地下水シミュレーション

THCHICAL SEMENAR ON

GROUNDWATER SIMULATION

Part 4

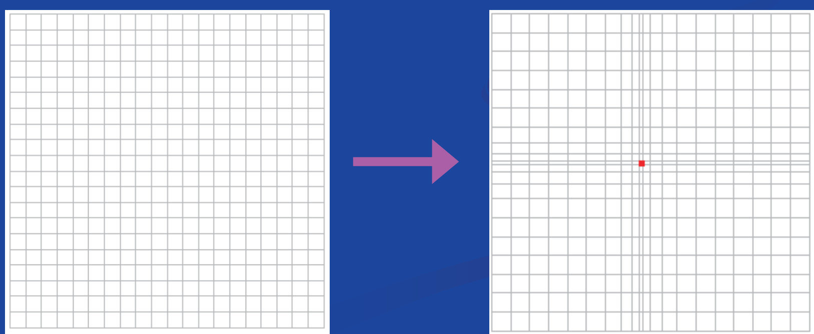
Functions and Main Packages

in Modflow based Program

89

Grid Specification and Modification

- Number of rows and columns
- Side length of grids
- Coordinates specification



90

Layer Properties Specification

- Confined Aquifer
- Unconfined Aquifer
- Confined / Unconfined Aquifer
- Horizontal Anisotropy
- Vertical Anisotropy

91

Boundary Specification

For groundwater flow simulation

- Active variable-head boundary
- Fixed-head or time-varying specified-head boundary
- Inactive and inactive boundary

For substance transport simulation

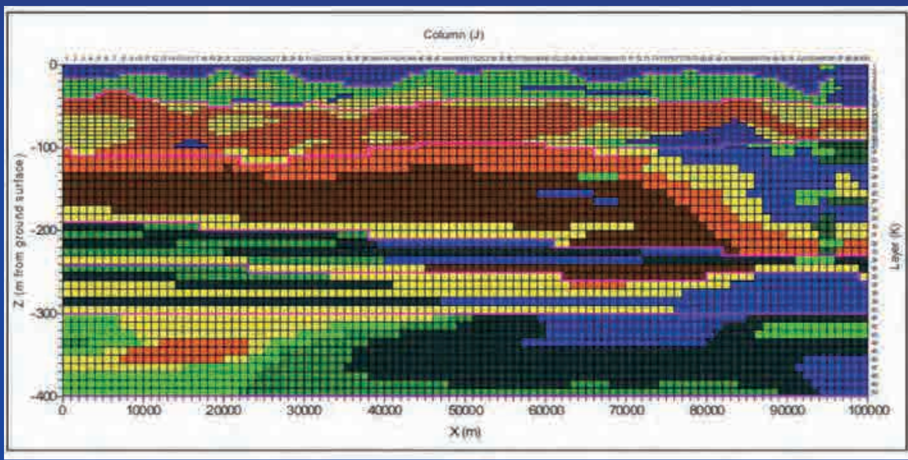
- Active concentration boundary
- Constant concentration boundary
- Inactive concentration boundary

92

WS-6 : 地下水シミュレーション

Layer Top and Bottom Elevation

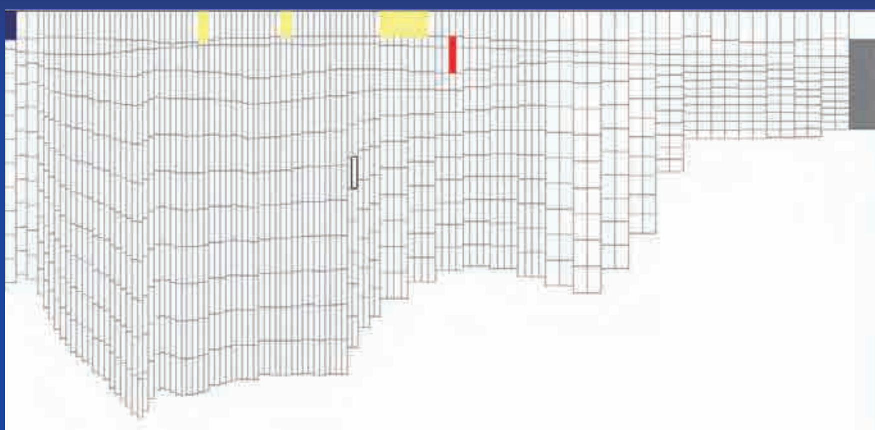
Example 1: uniform layer elevation specification



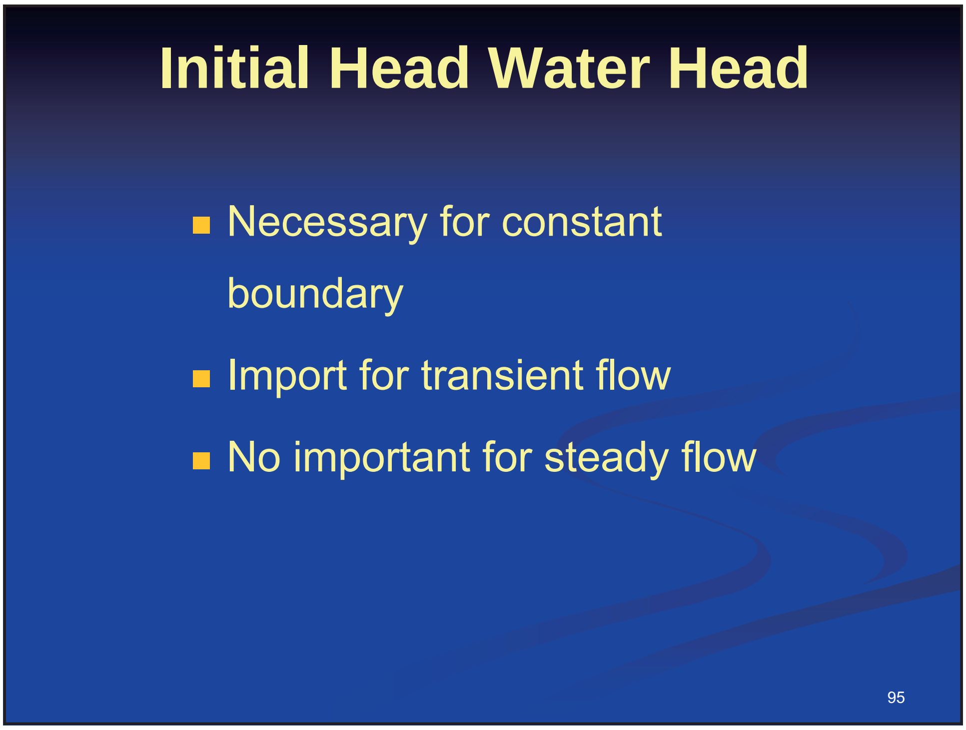
93

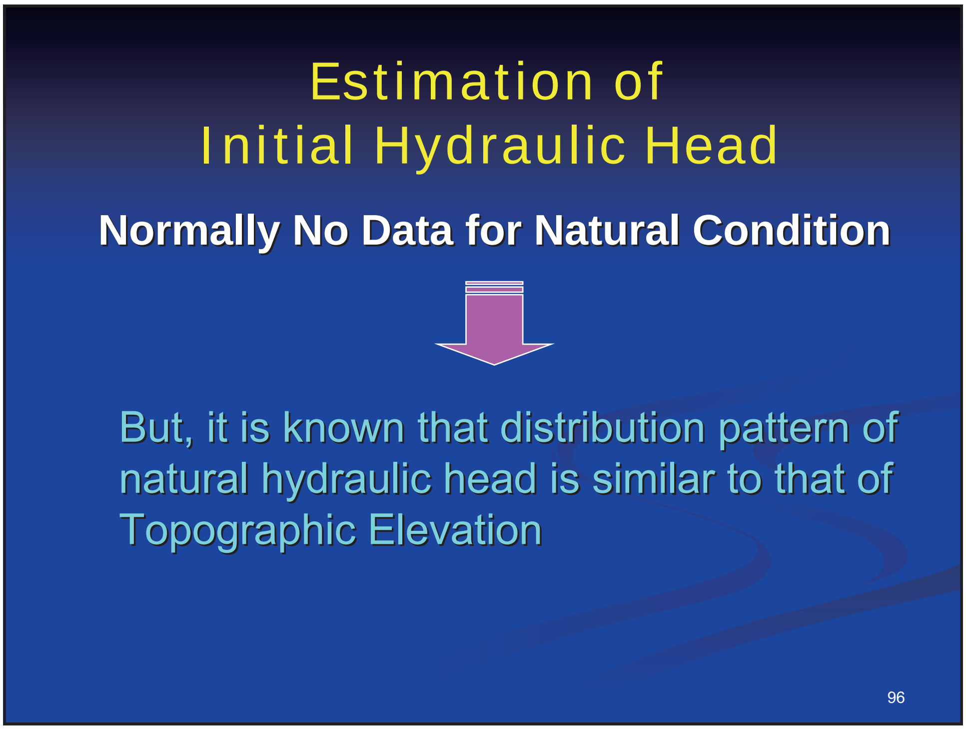
Layer Top and Bottom Elevation

Example 2: nonuniformity layer elevation specification

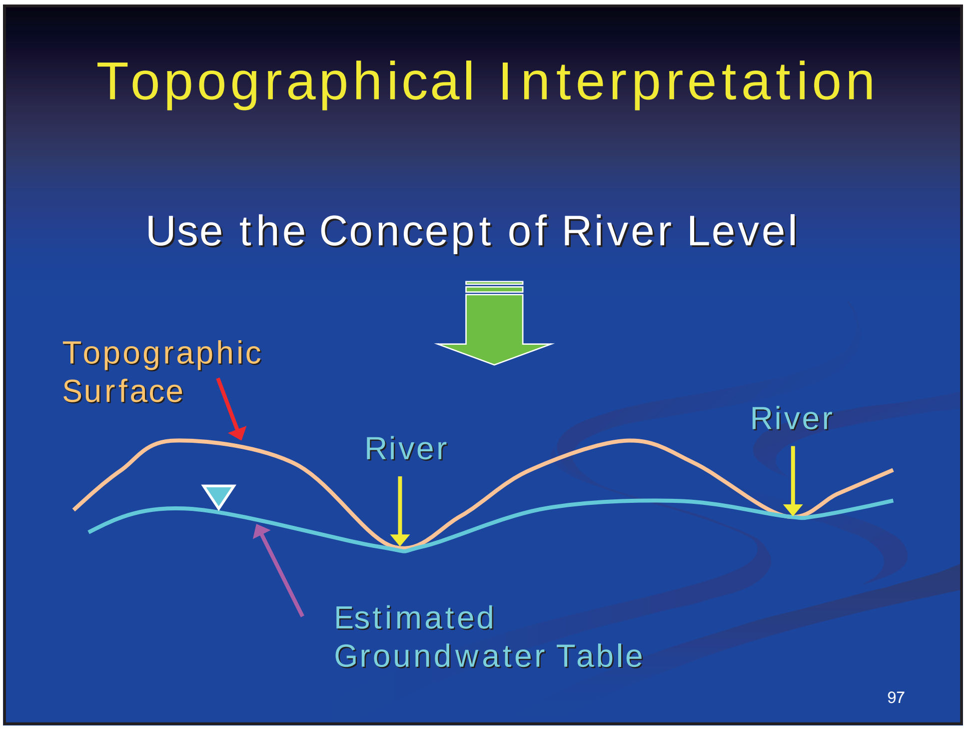


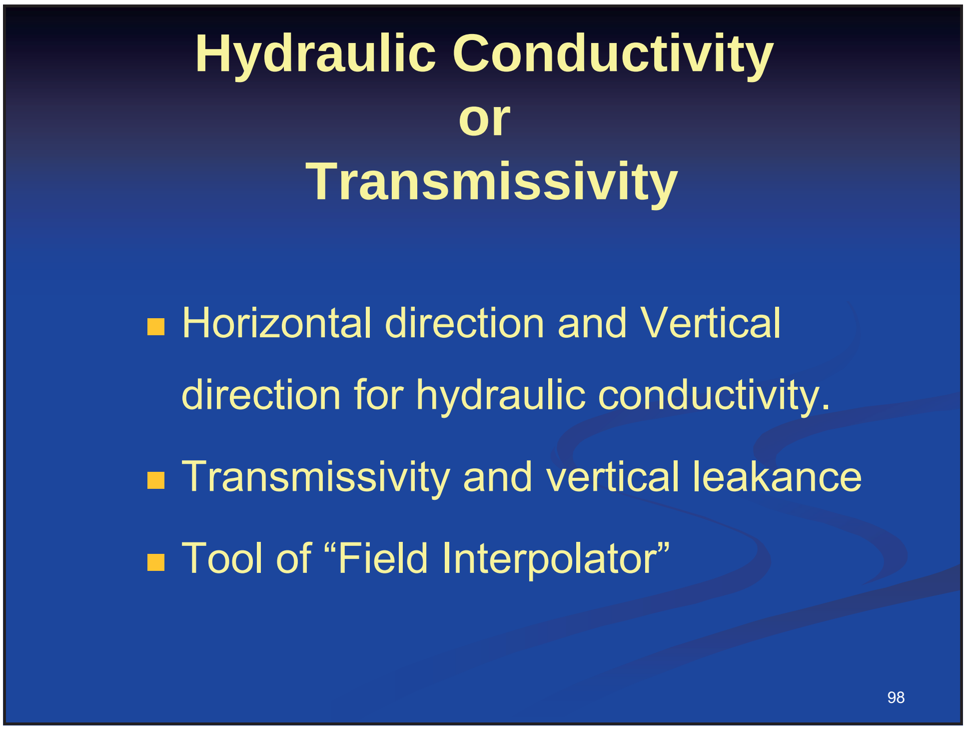
94

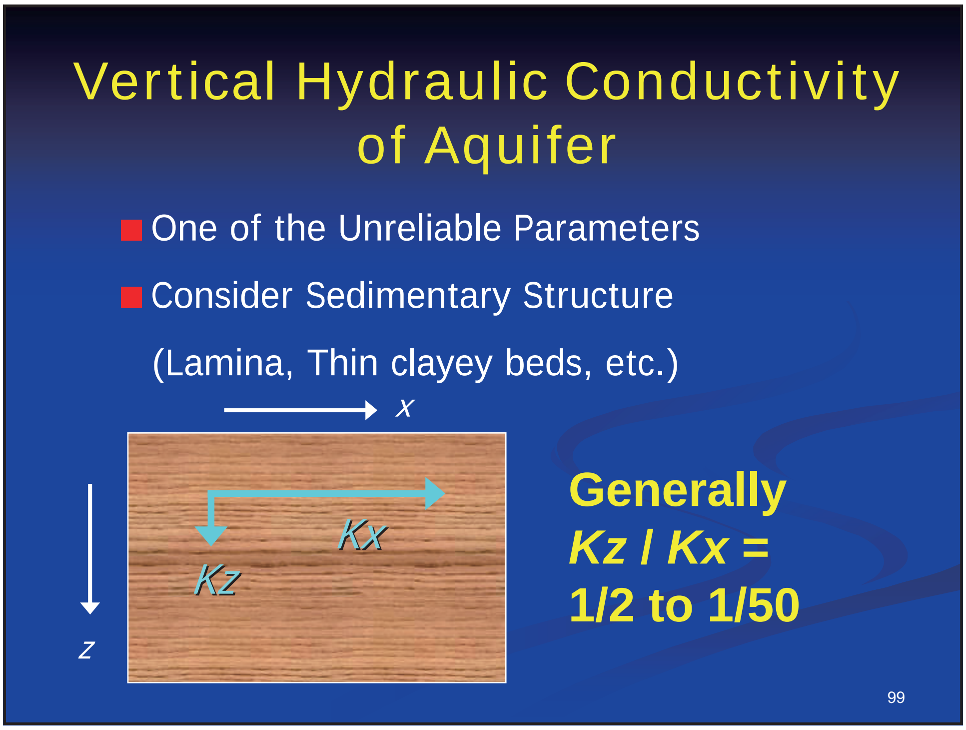

Initial Head Water Head
Necessary for constant boundary
Import for transient flow
No important for steady flow
95

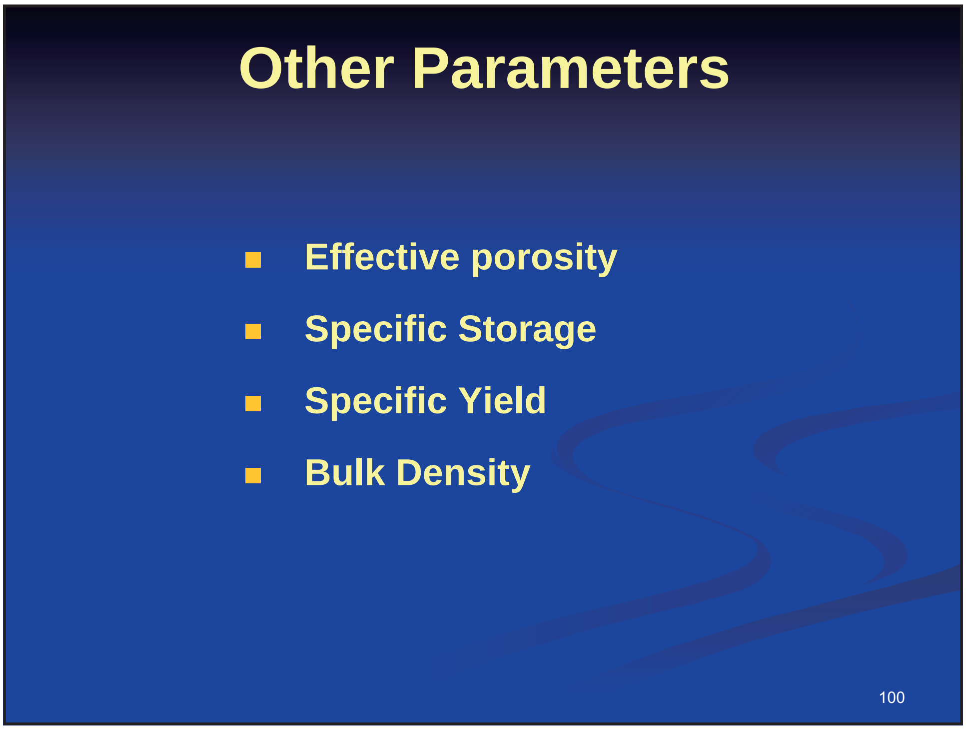

Estimation of
Initial Hydraulic Head
Normally No Data for Natural Condition
But, it is known that distribution pattern of natural hydraulic head is similar to that of Topographic Elevation
96

WS-6 : 地下水シミュレーション






Vertical Hydraulic Conductivity of Aquifer
One of the Unreliable Parameters
Consider Sedimentary Structure
(Lamina, Thin clayey beds, etc.)
x
z
Kx
Kz
Generally
Kz / Kx =
1/2 to 1/50
99


Other Parameters
Effective porosity
Specific Storage
Specific Yield
Bulk Density
100

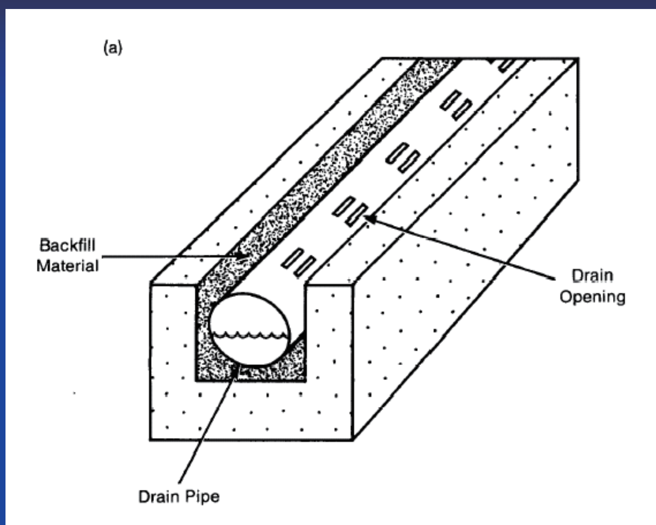
MODFLOW Drain Package

- **Purpose:**

  To simulate effects of features such as agricultural drains, which remove groundwater from aquifer at a rate proportional to the head difference between the aquifer and the drain.

101

Concept Drain Package (1)



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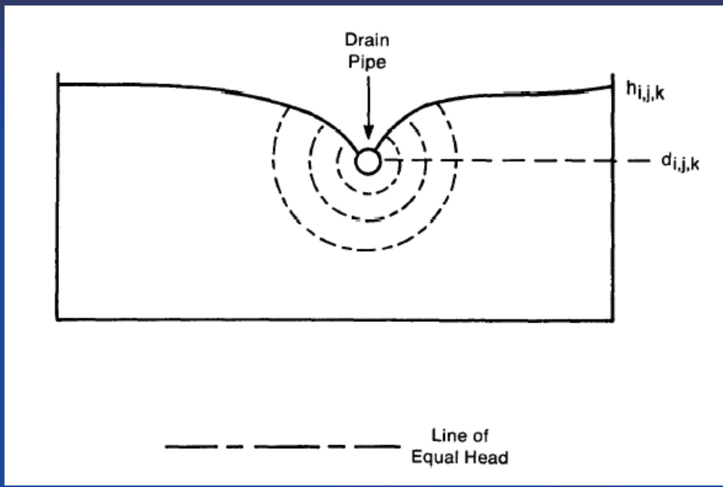
Concept Drain Package (2)



103

Evaporation Package

Three parameters

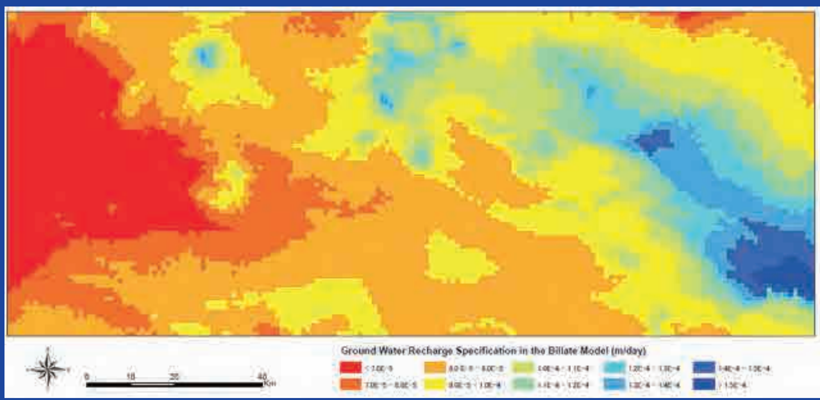
- Maximum Et rate (L/T)
- Elevation of the surface (L)
- ET extinction Depth (L)

104

Recharge Package

One parameter: Recharge Flux (L/T)

Example of Recharge package specification for the Billate River basin groundwater simulation model:



105

General Head Boundary

Purpose: solve the problem of the implicit specification of inactive cell for the domain boundary. Two parameters:

- **Hydraulic conductance (L^2/T)**
- **Head on the external source (L)**

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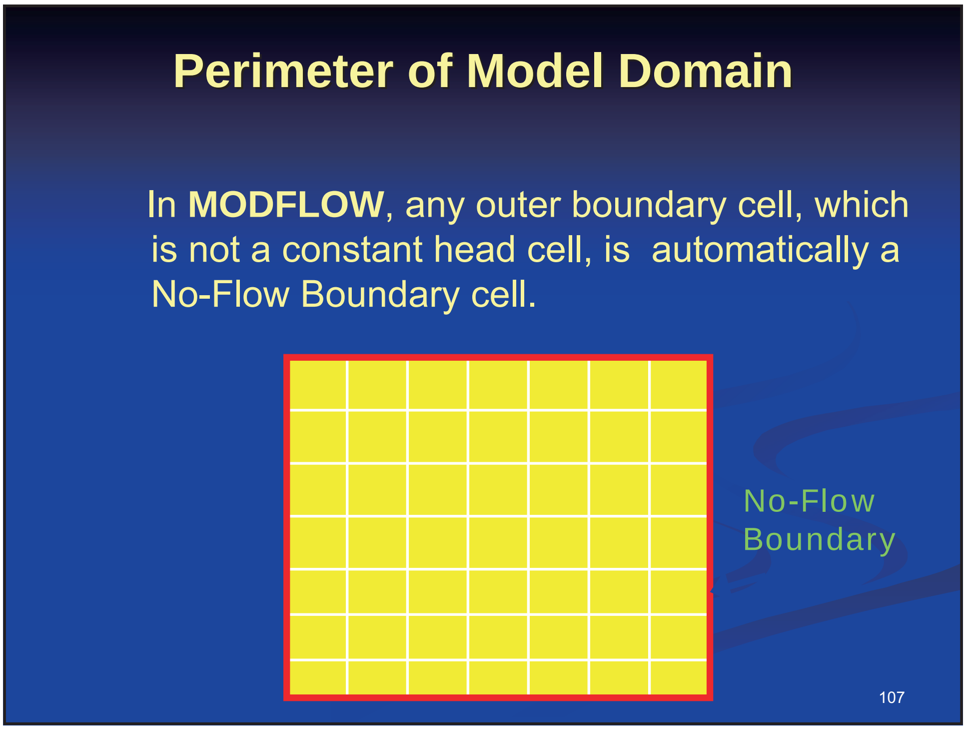
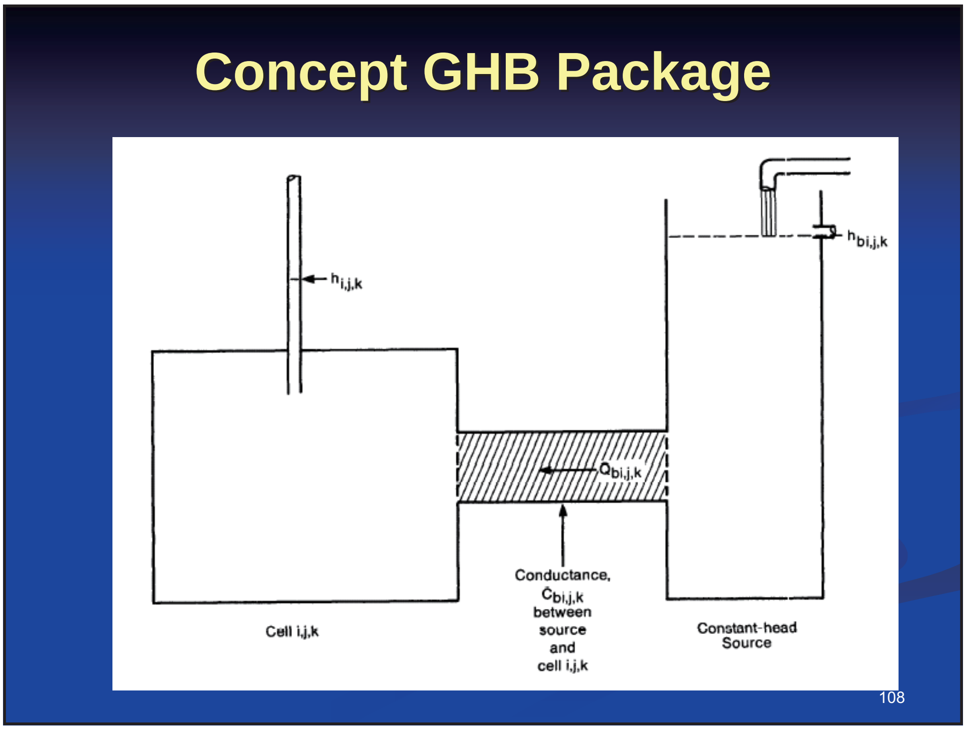
WS-6 ： 地下水シミュレーション





How to Calculate Q_{GHB}

$$Q_{GHB} = C_{GHB} \left(h_b - h \right)$$

where,

Q_{GHB} : Flow through GHB Cell [L^2/T]

C_{GHB} : GHB Hydraulic Conductance

h_b : Head on the External Source

h : Hydraulic Head in the Aquifer

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GHB Hydraulic Conductance C_{GHB}

$$C_{GHB} = K * L$$

where,

K : Equivalent Hydraulic Conductivity

L : Length of the General-Head Boundary within the Cell

⇩

Similar to the River Package and Drain Package

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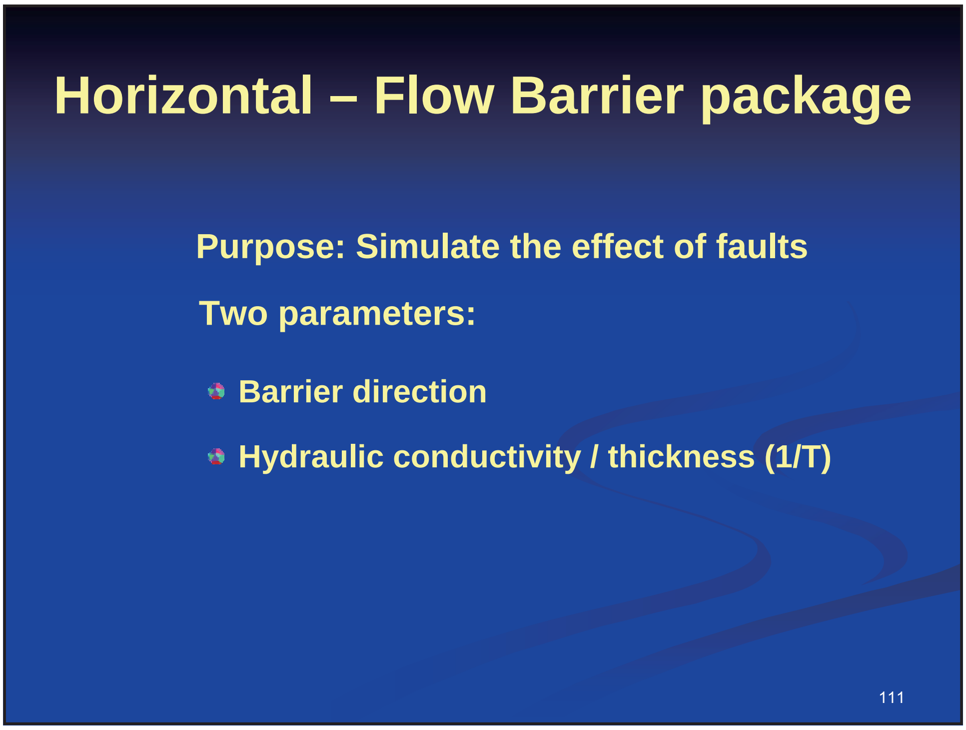
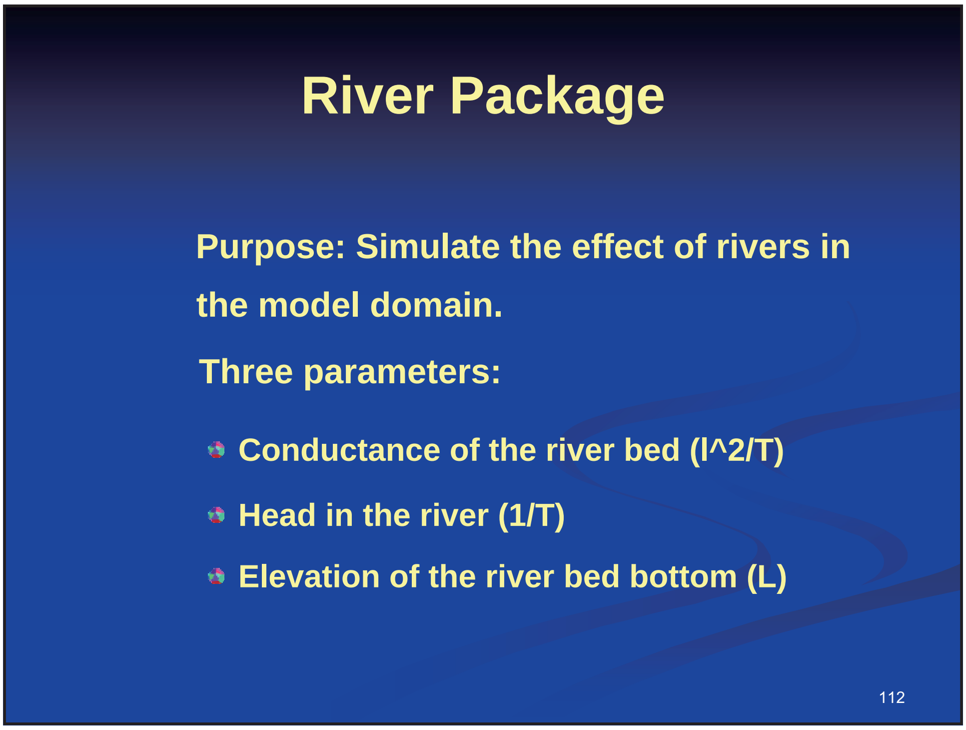
WS-6 ： 地下水シミュレーション





MODFLOW River Package

- **Purpose:**

  To simulate the effect of flow between groundwater systems and surface water features, such as rivers, lakes or reservoirs.

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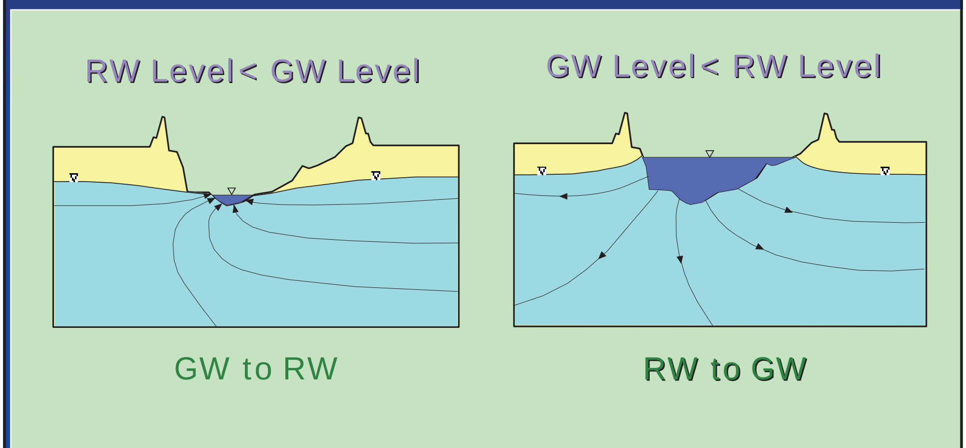
Relation between Groundwater and River Water



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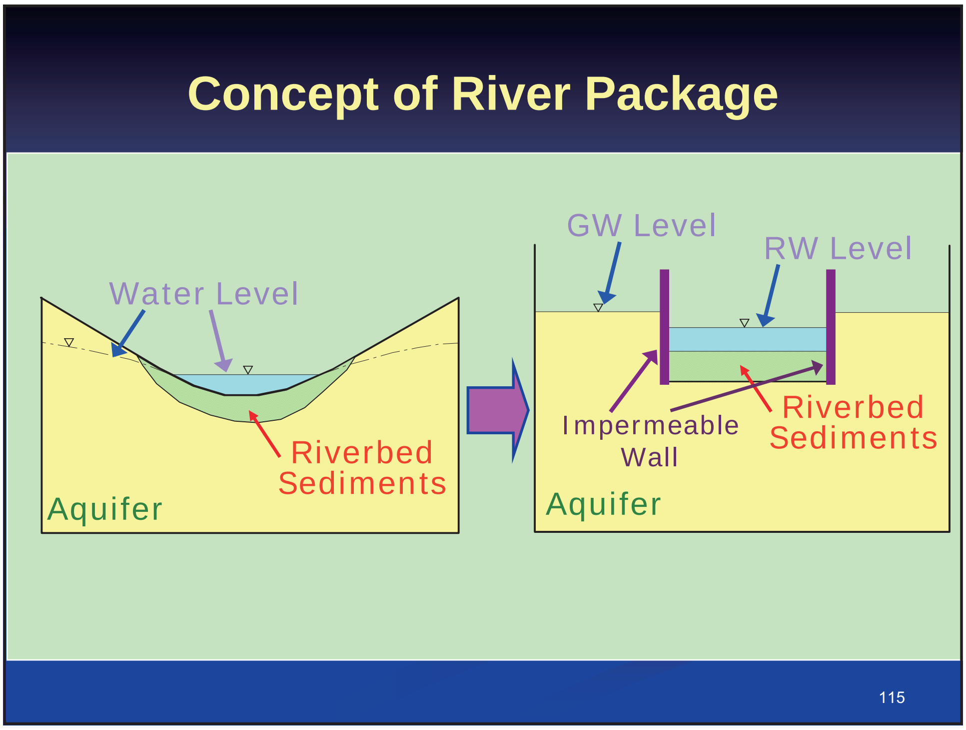
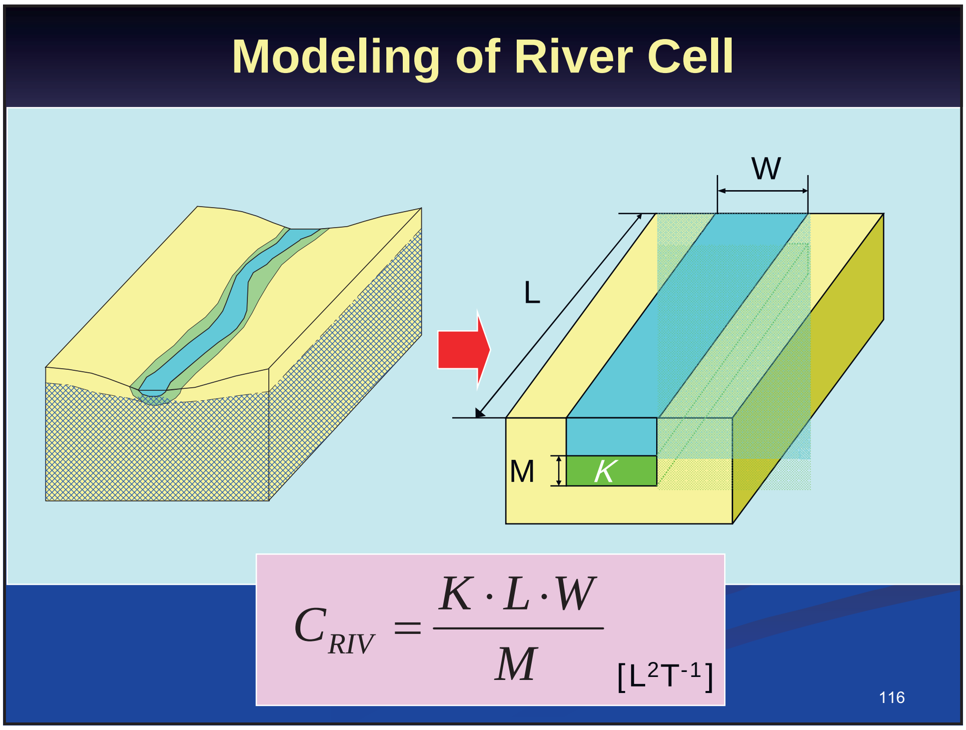
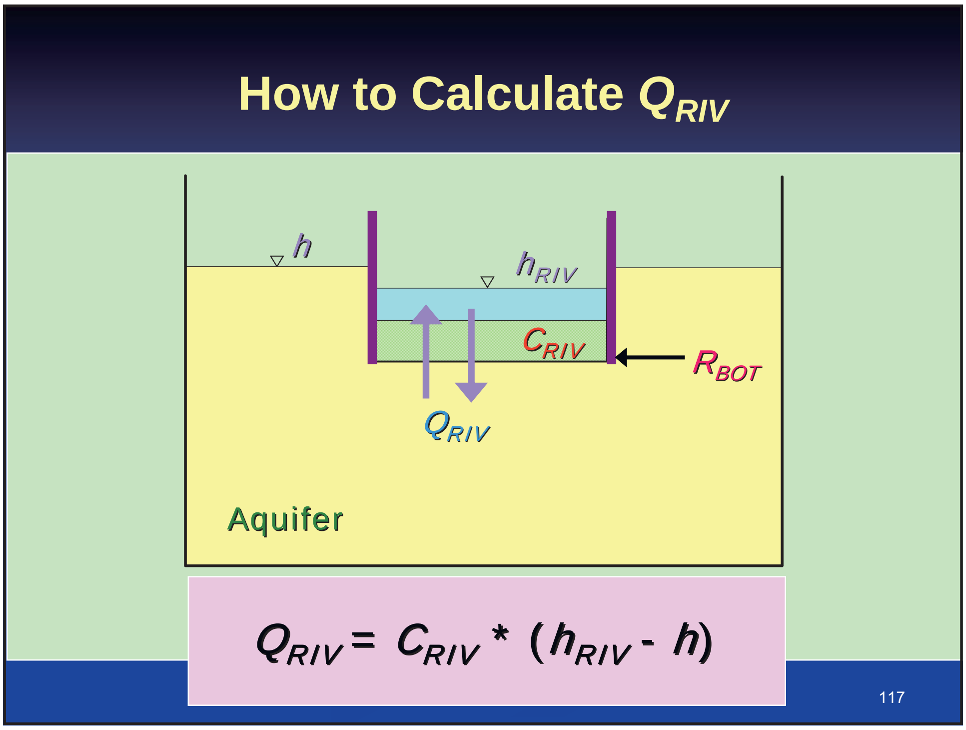
WS-6 : 地下水シミュレーション

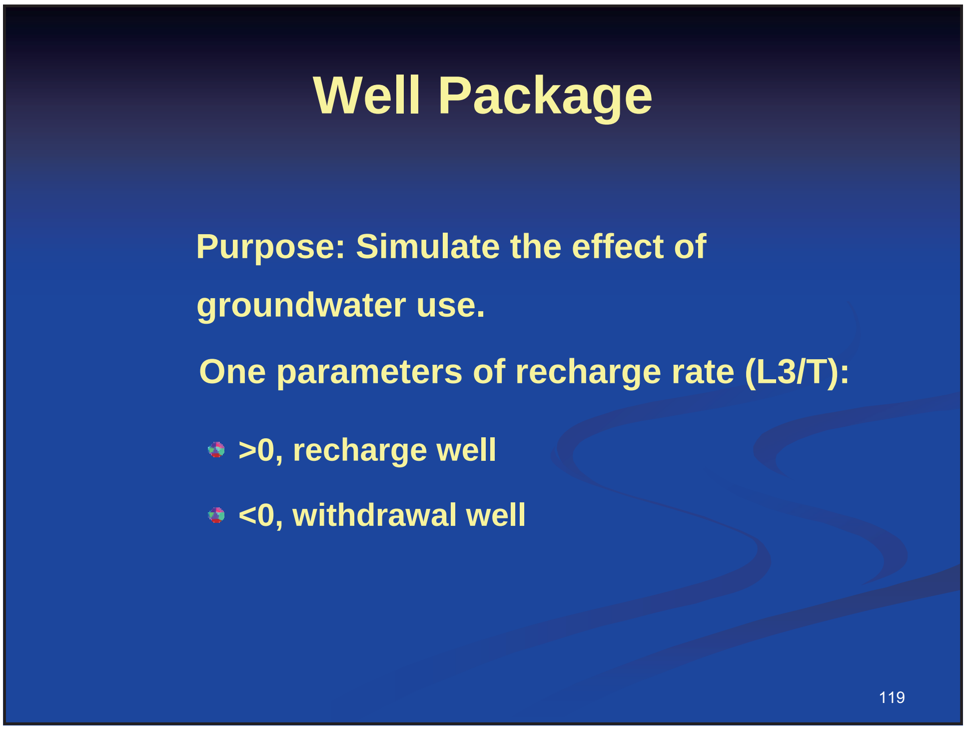


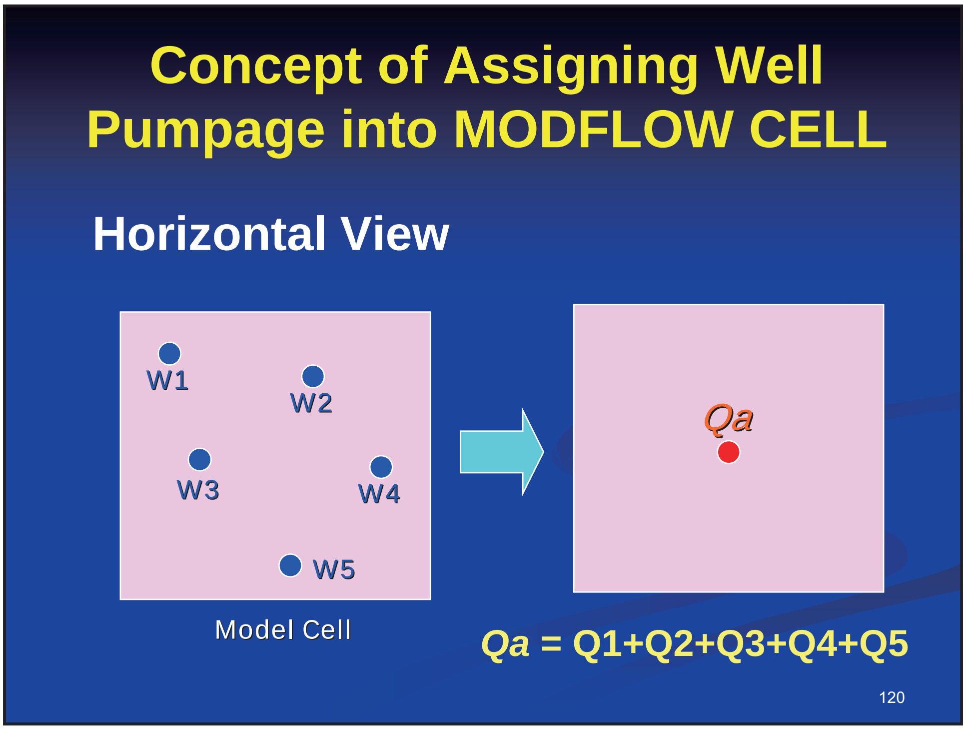



How to Calculate Q_{RIV}
h
h_{RIV}
C_{RIV}
R_{BOT}
Q_{RIV}
Aquifer
$Q_{RIV} = C_{RIV} * (h_{RIV} - h)$
117


River Package
Example of river package specification for the Billate River basin groundwater simulation model:
Boundary Specification
River
Lake
Inactiver Boundary
0 5 10 20 30 40
Km
118

WS-6 ： 地下水シミュレーション

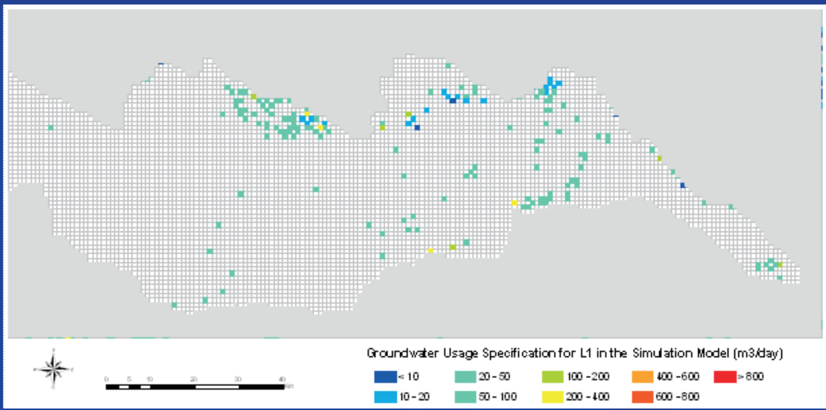




WS-6 ： 地下水シミュレーション

Well Package

Example-1: well package specification for the Billate River basin groundwater simulation model layer_1



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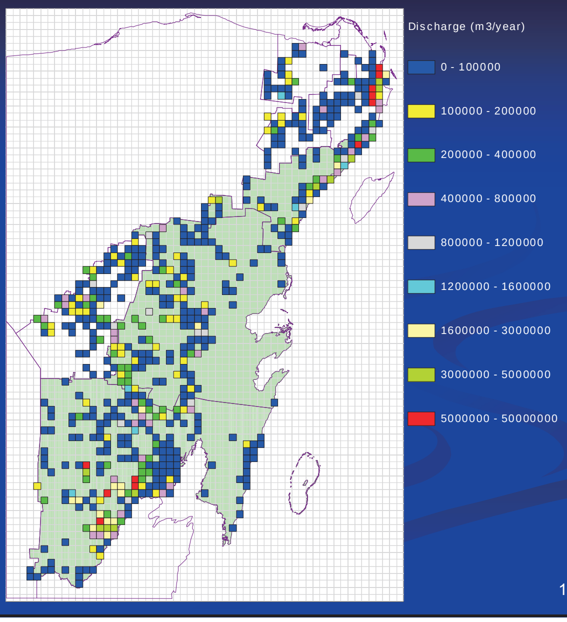
Well Package

Example-2:

well package specification for the area of Quintana Roo State, Mexico



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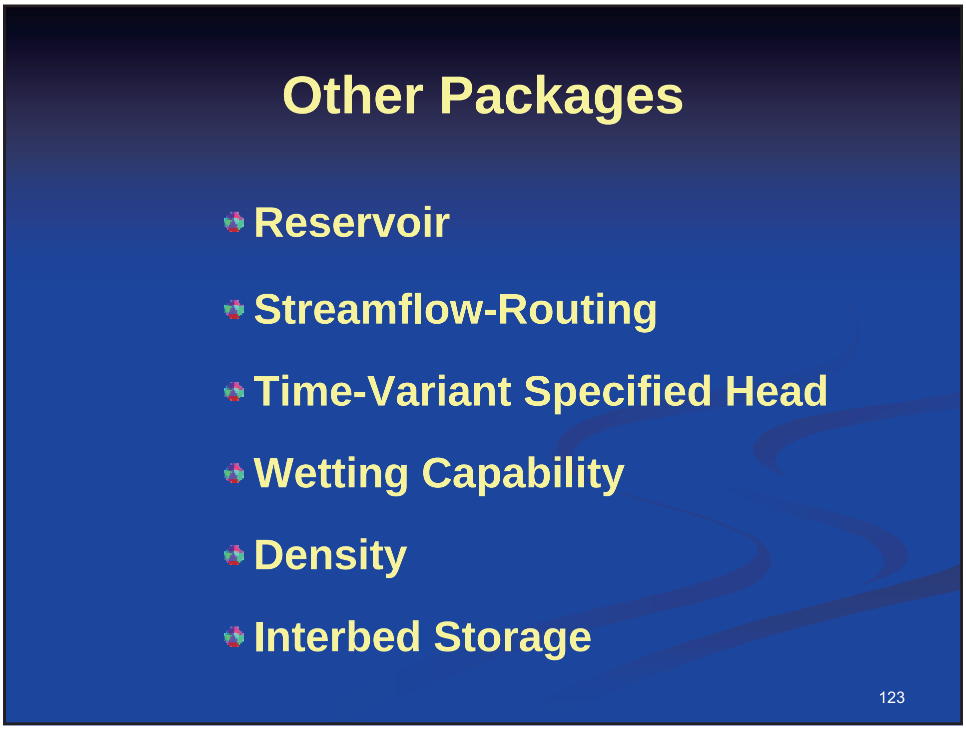
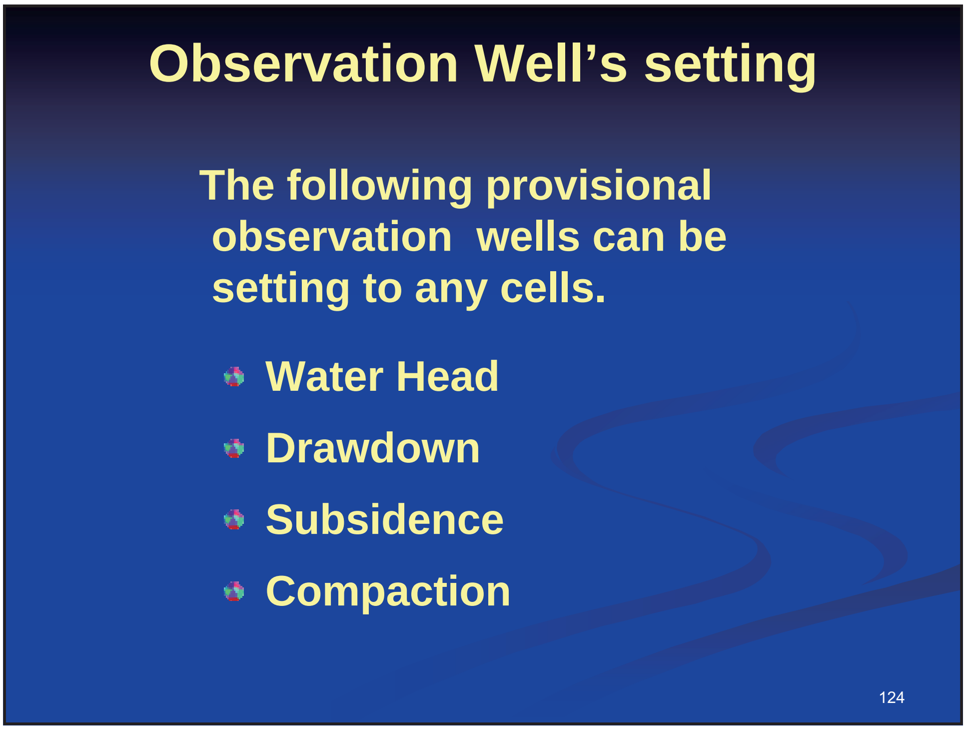
WS-6 ： 地下水シミュレーション





Solver Selection and Parameter Setting

Different solutions can be selected:

- DE45…
- PCG2
- SIP
- SSOR

Different parameters can be set:

- Out Iteration
- Inner Iteration
- Head Change
- Residual and so on

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Model Error Check

The following data will be checked:

- 1. Geometrical setup of the model
- 2. Starting head at constant head cells
- 3. Time-independent data (if used)
- 4. Horizontal hydraulic conductivity or Vertical hydraulic conductivity
- 5. Storage coefficient, specific storage or specific yield
- 6. All used packages

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Model Error Check

Example of error identification:

>>>GEOMETRICAL SETUP

>>Thickness of layers:

Error: The thickness of the following active cell(s) is zero or negative. (COL, ROW, LAYER) (3,3,1)

Warning: The thickness of the following inactive cell(s) is zero or negative (COL, ROW, LAYER)

>>Starting head of constant head cells: --- OK ---

>>>TIME-INDEPENDENT DATA:

>>Effective porosity --- OK ---

>>>TIME-DEPENDENT DATA:

>WEL1 Package: --- OK ---

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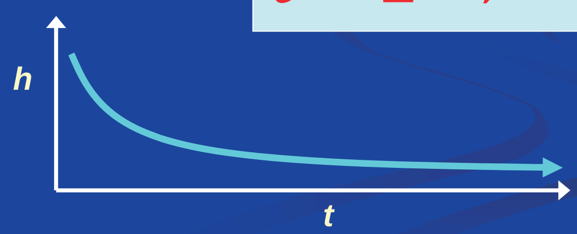
Simulation Flow Type Selection (1)

Steady-State

Not time dependent

time t: $t = 1 \rightarrow \infty$



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Simulation Flow Type Selection (2)

Transient

Time dependent
(Unsteady-state)

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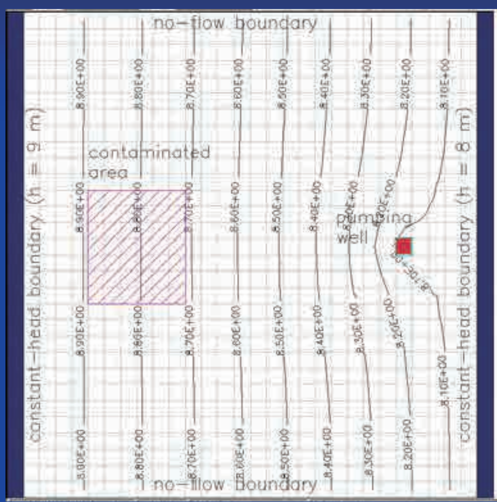
Groundwater Flow Simulation

Example: Result of PMWin Pro tutorials.



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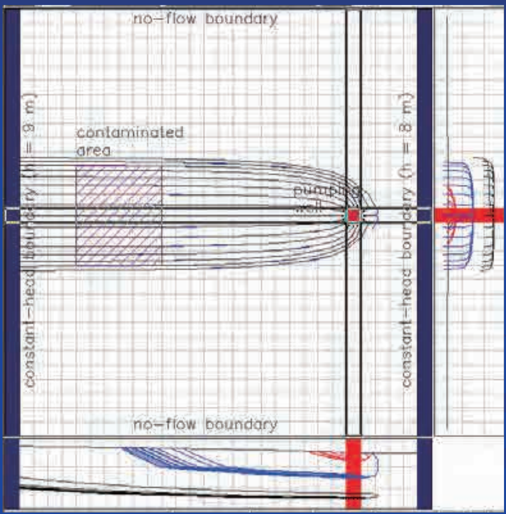
WS-6 : 地下水シミュレーション

Groundwater Flow Simulation

Example: Result of PMWin Pro tutorials.



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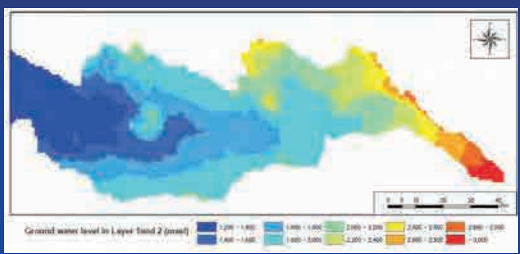
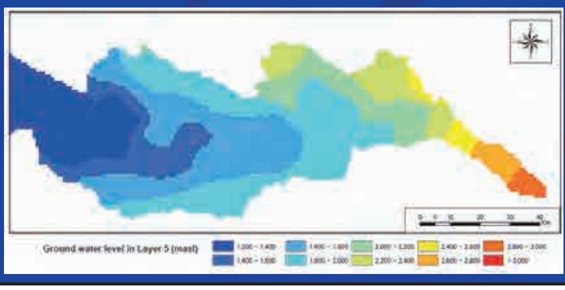
Groundwater Flow Simulation

Example: Water head distribution in Billate River basin.



Water level in layer_1



Water level in layer_5

Solute Transport Simulation

Using Advection-Dispersion equation (Konikow and Bredehoeft, 1978)

$$\frac{\partial C_n}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij} \frac{\partial C_n}{\partial x_i} \right) - \frac{\partial}{\partial x_i}\left(C_n V_i \right) - \frac{C'_n W}{\varepsilon}$$

D_{ij} : Coefficient of hydrodynamic dispersion (a second order tensor) (L^2T^{-1})
V_i : Seepage velocity in the direction of x_i (LT^{-1})
C_n : Concentration of the *n*th constituent (ML^{-3})
C'_n : Concentration of the *n*th constituent in the source or sink fluid (ML^{-3})
ε : Effective porosity (dimensionless).

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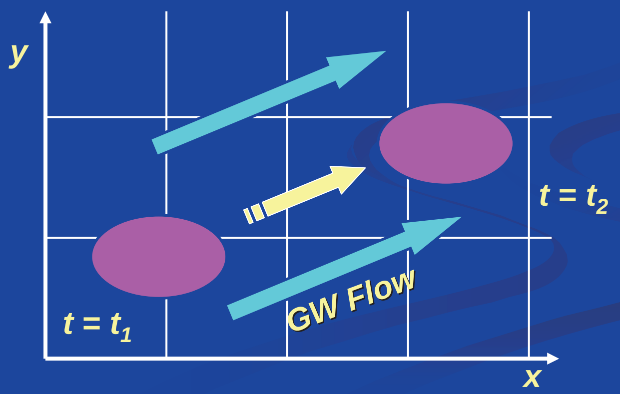
Advection

The process by which solutes are transported by moving groundwater. (= Convective Transport)



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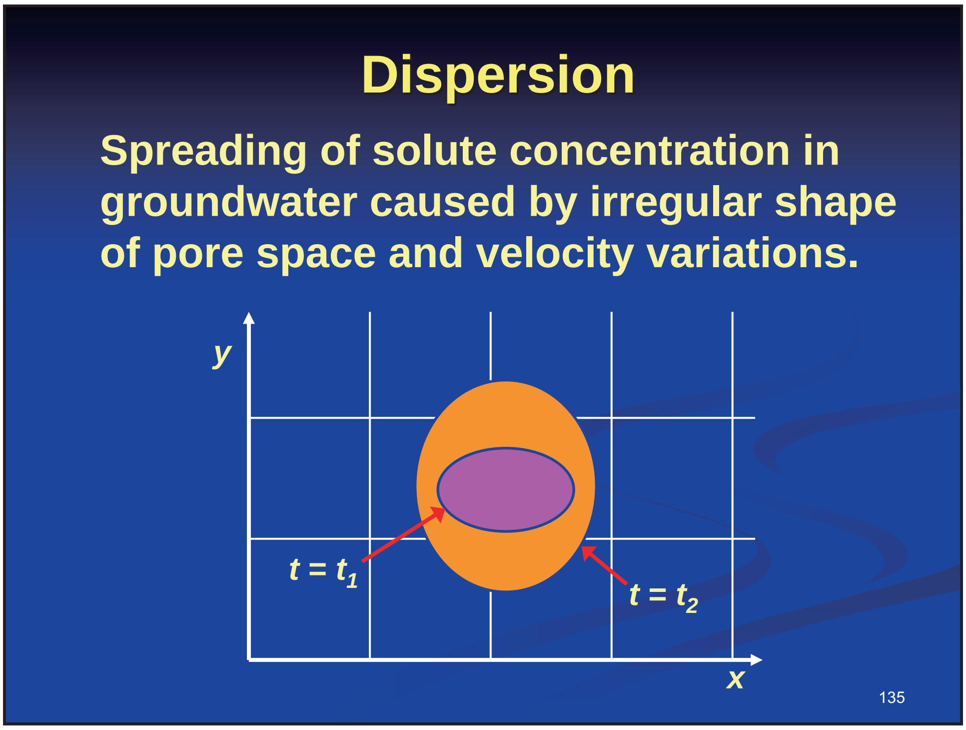
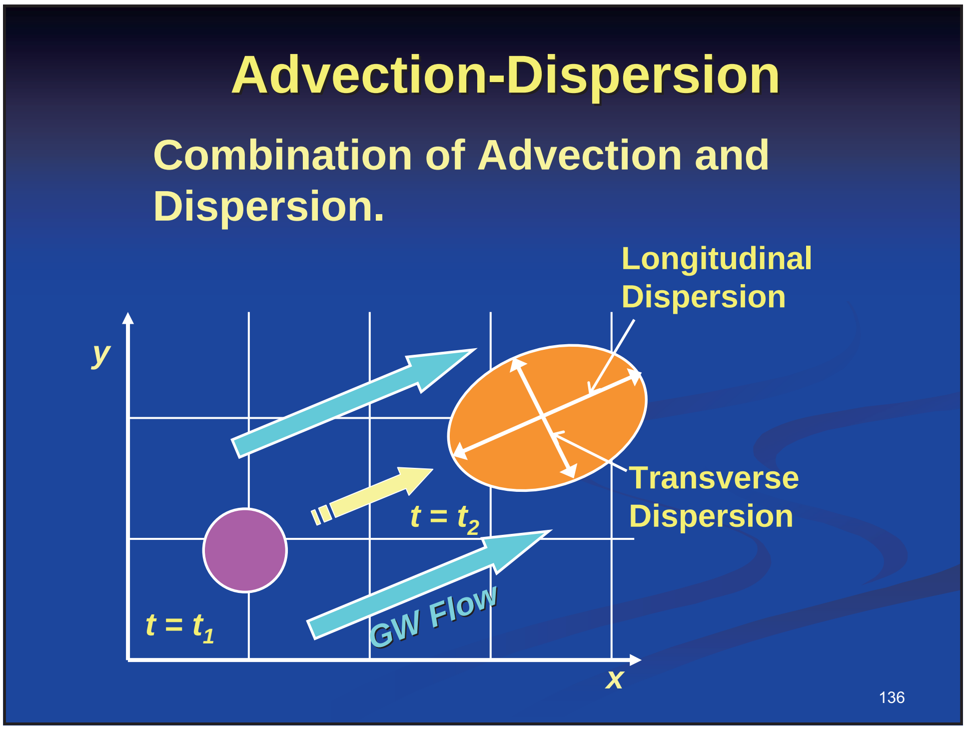
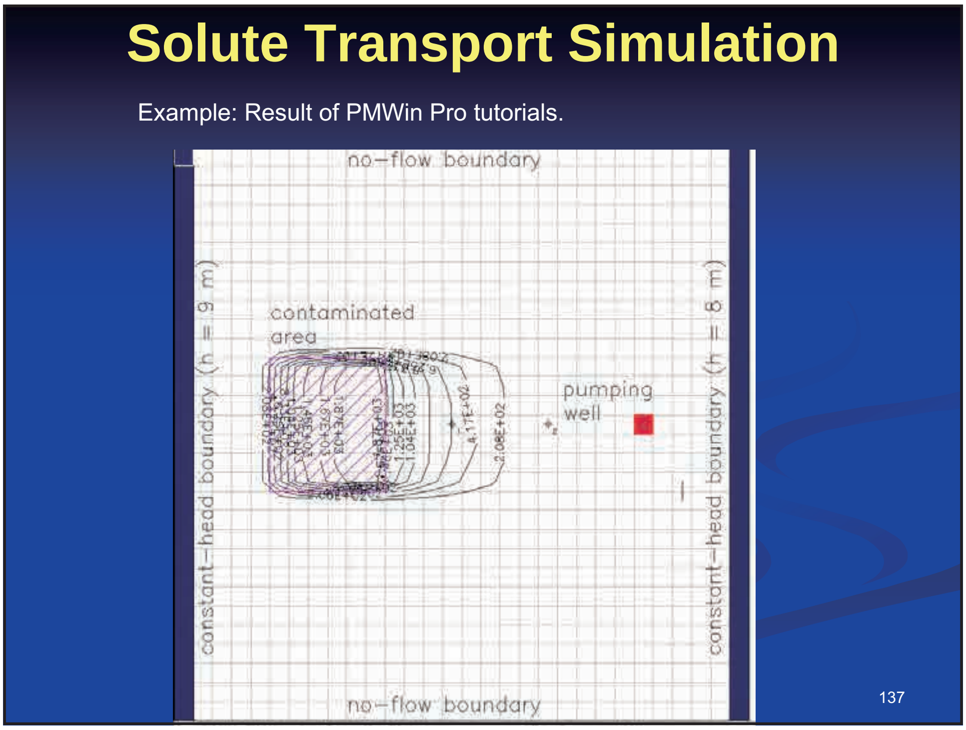
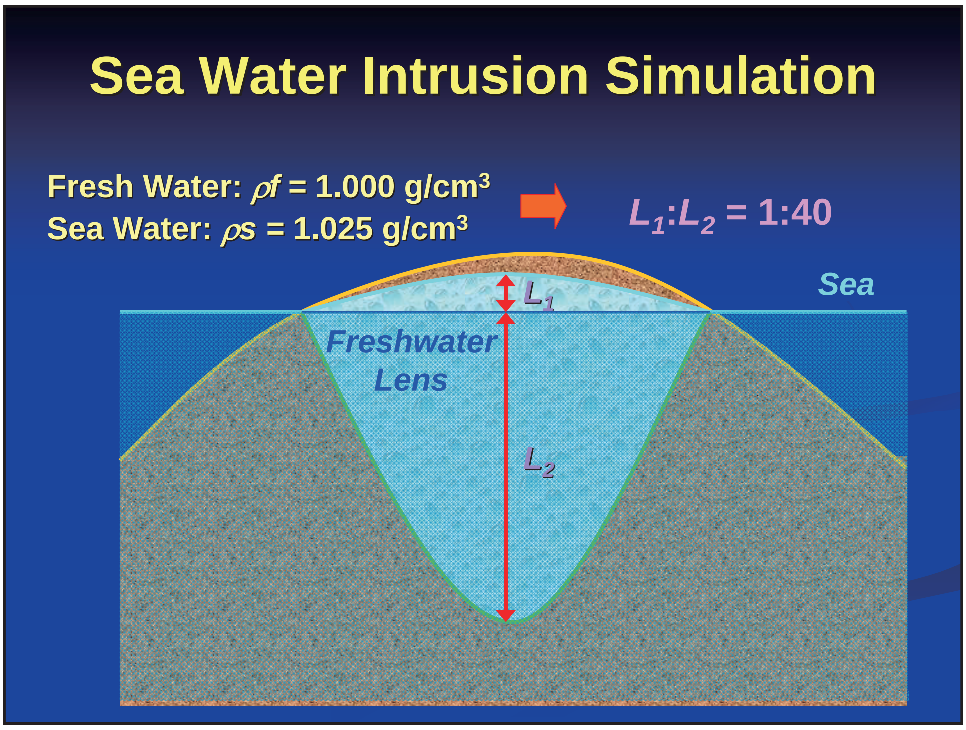
WS-6 ： 地下水シミュレーション



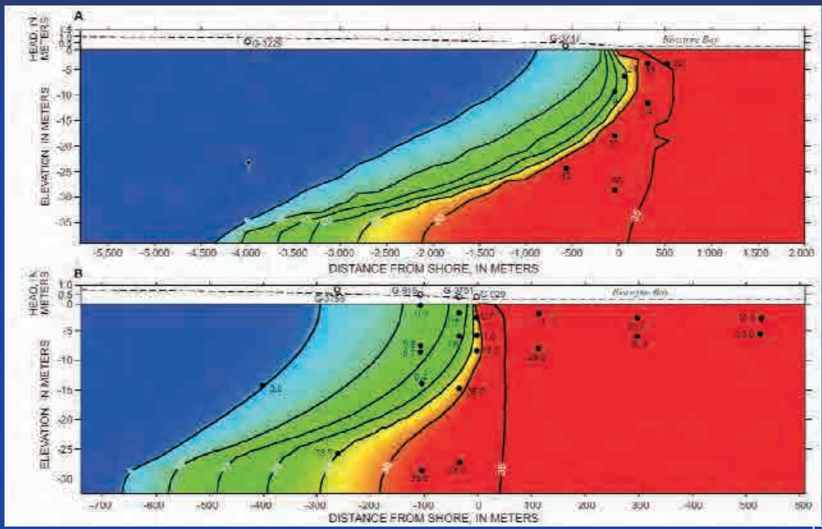



Solute Transport Simulation
Example: Result of PMWin Pro tutorials.
no–flow boundary
contaminated area
pumping well
constant–head boundary (h = 9 m)
constant–head boundary (h = 8 m)
no–flow boundary
137


Sea Water Intrusion Simulation
Fresh Water: ρf = 1.000 g/cm³
Sea Water: ρs = 1.025 g/cm³
L1:L2 = 1:40
Sea
L1
Freshwater Lens
L2

Seawater Intrusion Simulation

Density Fluid Model can simulate Ghyben-Herzberg Principle



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The Type Classification of Groundwater Simulation Model

All models in the world can be simply classified into 3 ranks

- WHITE MODEL
- BLACK MODEL
- GRAY MODEL

Groundwater simulation model is never a WHITE MODEL, but also not a BLACK MODEL. The suitable classification should be considered as a GRAY MODEL.

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