# Daftar Isi

# Bab I
# Pendahuluan

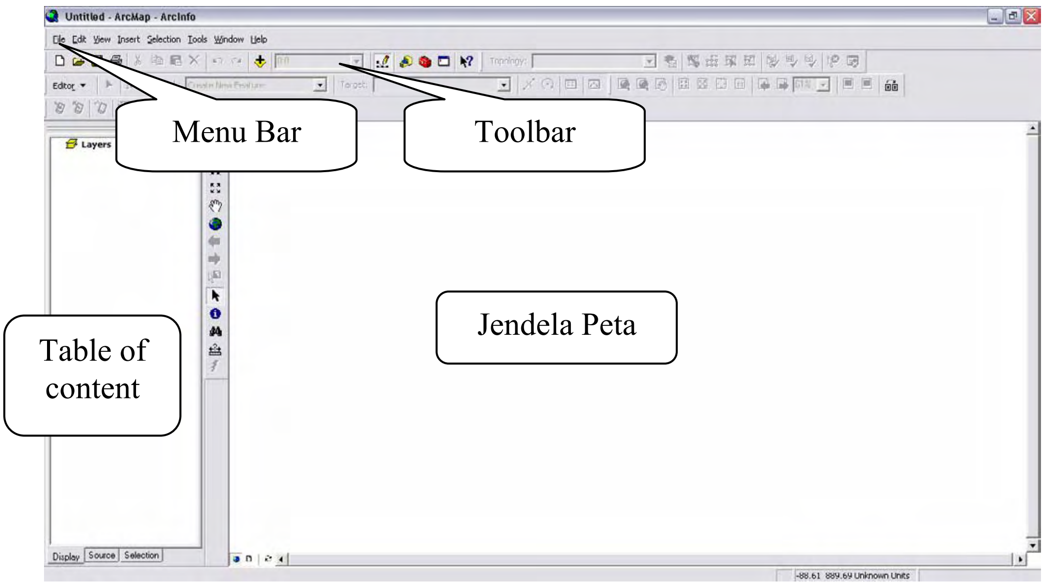
Pada bab ini akan dijelaskan mengenai program ArcGIS 9.0, Model Builder dan kemampuan yang dimilikinya sebagai alat pemodelan.

ArcGIS 9.0 merupakan salah satu program pengolah data spasial dalam sebuah Sistem Informasi Geografis. Selain kemampuannya untuk menampilkan peta, memanipulasi tampilan dan untuk mencetak peta, program ini juga dilengkapi dengan fasilitas Model Builder yang merupakan alat pemrograman visual interaktif. Model Builder memiliki kemampuan untuk menghubungkan antara proses, data dan parameter.

Langkah-langkah awal penggunaan ArcGIS adalah sebagai berikut

1. Klik 

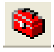
pada windows, ke Program lalu ArcGIS dan klik ArcMap.
2. Kotak dialog akan muncul dengan pilihan 'A new empty map', 'A template' atau 'An existing map'. Pilih 'A new empty map lalu klik OK.
3. Tampilan program seperti gambar berikut.
4. Masukkan layer-layer yang diperlukan ke dalam table of content.

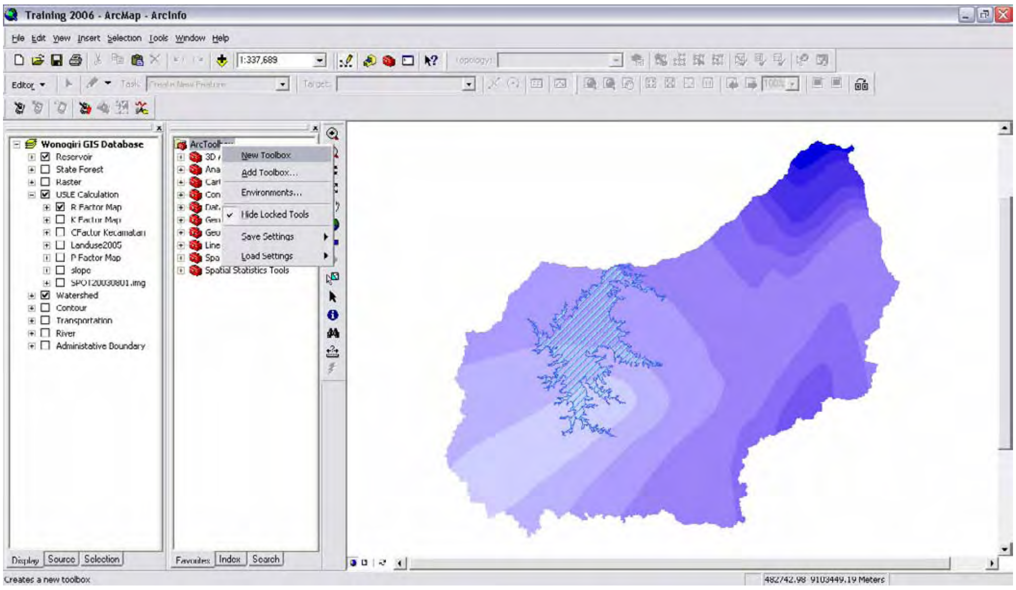



Keterangan

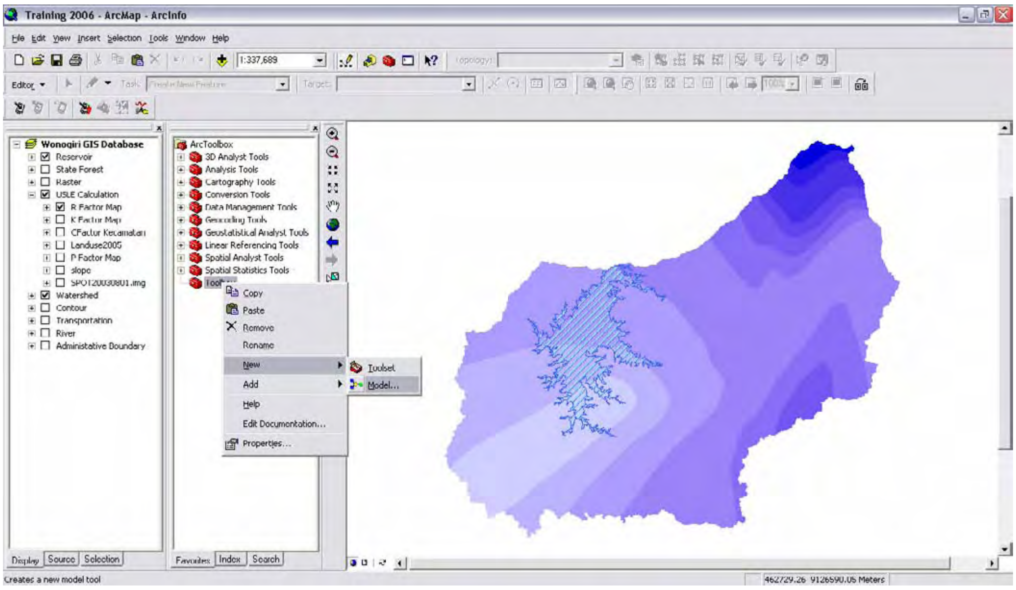
| | |
|---|---|
| Menu Bar | : menu pilihan untuk beragam fungsi. |
| Toolbar | : pilihan menu dengan menggunakan fungsi tombol. |
| Table of Content | : daftar layer peta yang digunakan/ditampilkan. |
| Jendela Peta | : tempat layer peta ditampilkan. |

Jika layer-layer yang diperlukan sudah dimasukkan ke dalam table of content dan sudah ditampilkan, maka data input untuk model sudah siap. Langkah-langkah berikut menerangkan untuk pembuatan model.

1. Tampilkan ArcToolbox dengan klik ikon .
2. Klik kanan pada ArcToolbox, pilih New Toolbox.

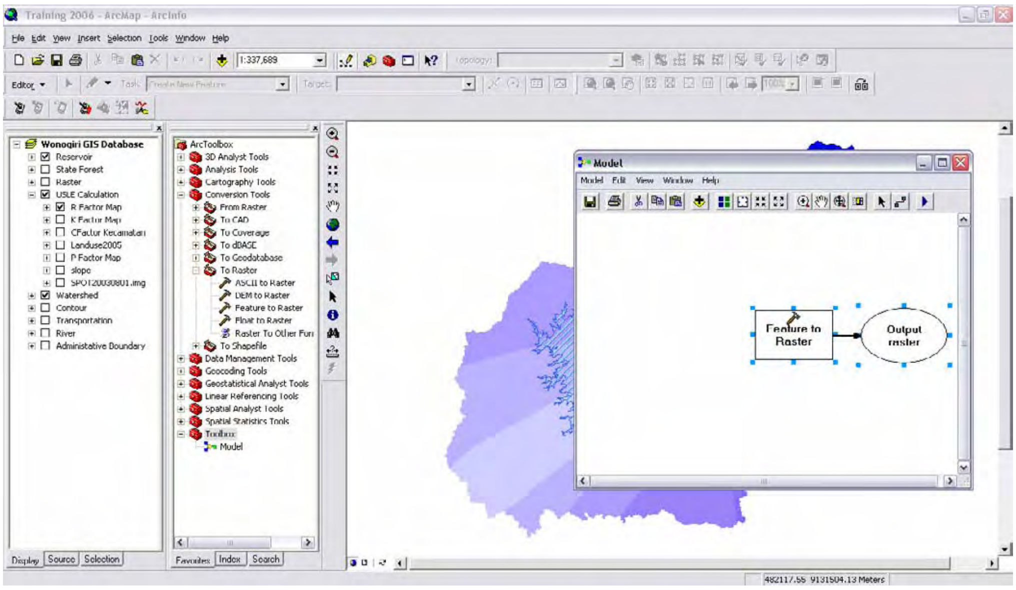



3. Klik kanan pada Toolbox, pilih New Model.

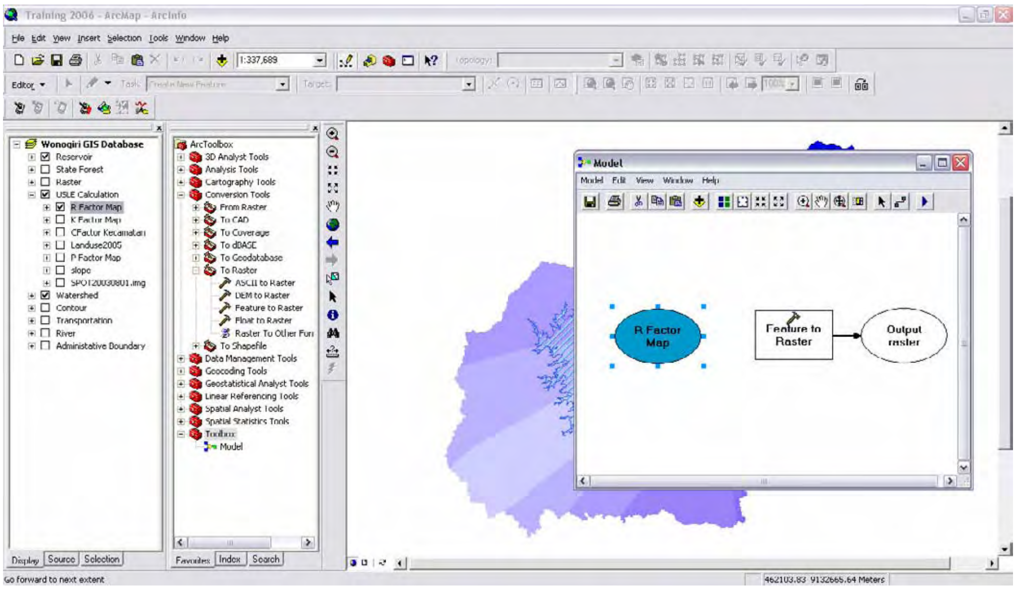



4. Jendela Model sudah terbuka. Seluruh Tool yang ada di daftar Toolbox bisa digunakan langsung di Model dengan cara drag and drop.

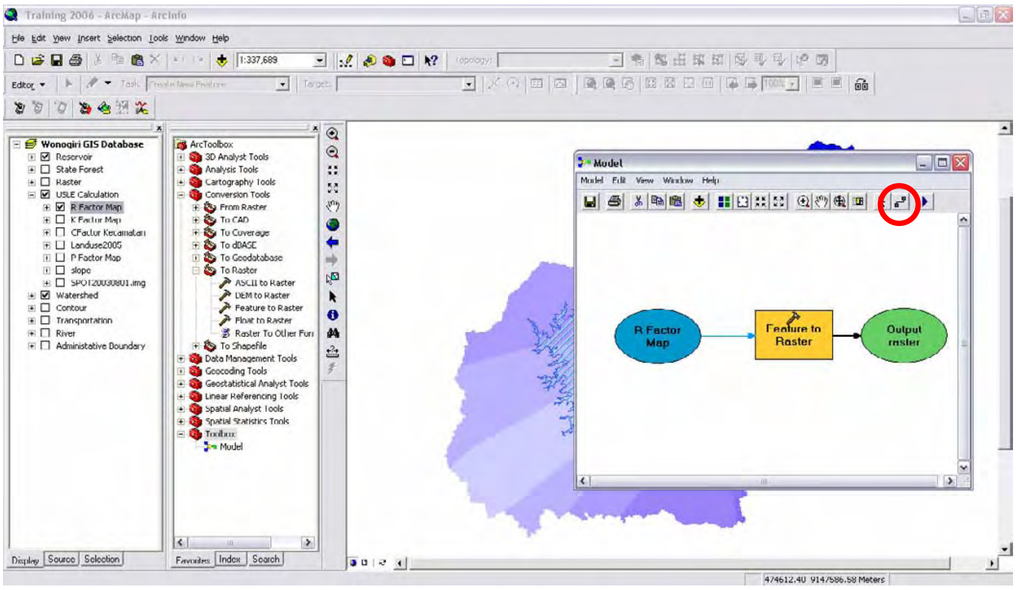
5. Sebagai awalan, masukkan tool Feature to Raster [ArcToolbox ↵ Conversion Tool ↵ To Raster ↵ Feature to Raster] ke dalam jendela model dengan cara drag and drop.

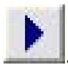


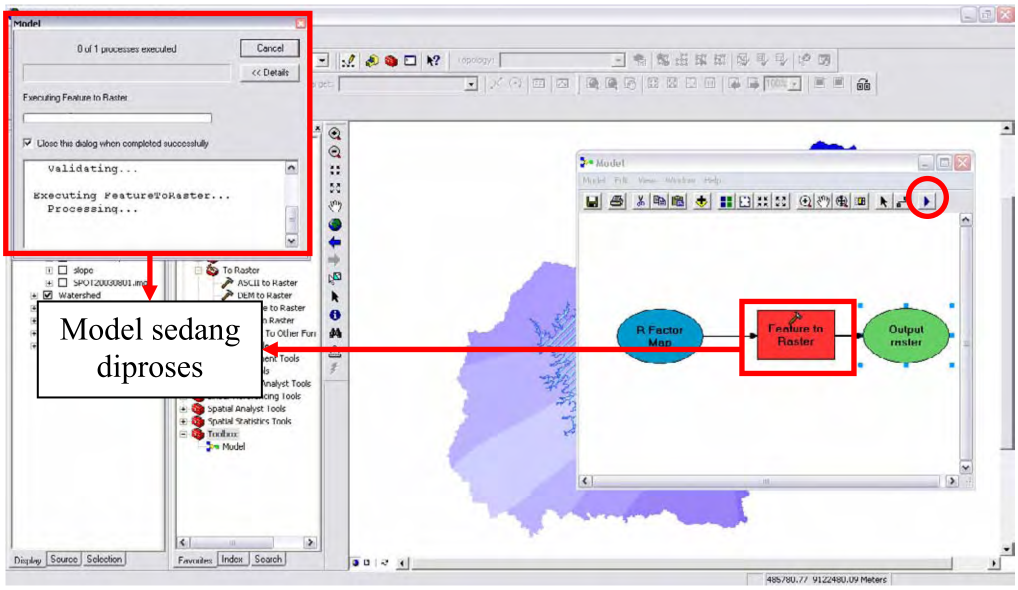

6. Masukkan data input R Factor Map dari table of content dengan cara drag and drop. R Factor map ini nantinya akan diubah dari shapefile menjadi raster.



7. Hubungkan data input dengan toolbox dengan menggunakan Add Connection .Jika warna toolbox berubah menadi kuning dan data output berubah menjadi hijau, maka toolbox tersebut siap untuk digunakan.




8. Untuk run atau menjalankan model, klik tombol run . Toolbox yang sedang berjalan/diproses akan berubah menjadi merah dan keluar jendela kecil yang menjelaskan perkembangan proses yang terjadi.




9. Jika proses sudah selesai berjalan, akan muncul bayangan pada tool dan data output. Jika perubahan dilakukan pada tool tersebut (misal: ada parameter atau data input yang diganti) maka bayangan tersebut akan hilang yang berarti proses belum dilakukan atau harus diulang kembali.

# Bab II

## Model Builder

Pada bab ini akan dijelaskan mengenai persamaan USLE, penggunaan Model Builder sebagai alat pemodelan persamaan USLE dan tool-tool yang digunakan beserta penjelasan dari tool-tool tersebut.

Persamaan USLE dihitung dengan mempertimbangkan faktor-faktor yang mempengaruhi erosi. Persamaan USLE sendiri adalah sebagai berikut :

$$A = R \times K \times L \times S \times C \times P$$

Masing-masing faktor akan dijelaskan dan dimodelkan menggunakan Model Builder dengan ukuran sel 20mx20m untuk mengakomodasi wilayah yang memiliki tingkat kemiringan tinggi.

### 1. Faktor R (erosivitas curah hujan)

Faktor erosivitas curah hujan dihitung dari peta faktor R (R Factor Map) yang dibuat bekerjasama dengan Hydrology Expert. Besarnya nilai faktor erosivitas curah hujan sudah dimasukkan ke dalam field "total".


Gambar 2.1. Model faktor R

Untuk faktor R, tool yang digunakan adalah :

- Feature to Raster (Feature to Raster R)
  a. Input : R Factor Map
  b. Variable
     - Field : total
     - Output cell size : 20
  c. Output : RRaster

### 2. Faktor K (erodibilitas tanah)

Faktor erodibilitas tanah dihitung dari peta faktor K (K Factor Map) yang dibuat berdasar peta jenis tanah (soil map) dengan modifikasi berdasarkan survei yang dilakukan oleh Geology Expert. Besarnya nilai erodibilitas tanah sudah dimasukkan ke dalam field "Rect_Kfact".

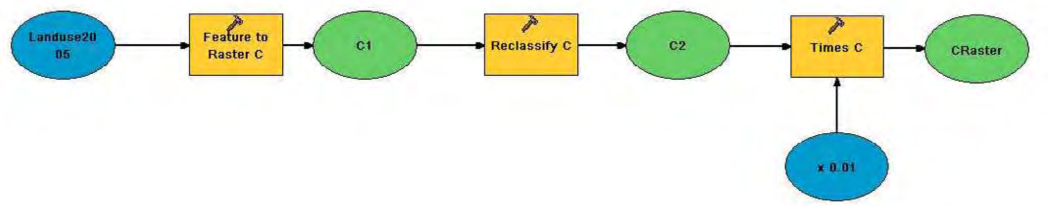

Gambar 2.2. Model faktor K

Untuk faktor K, tool yang digunakan adalah :

- Feature to Raster (Featue to Raster K)
  - a. Input : K Factor Map
  - b. Variable
    - Field : Rect_Kfact
    - Output cell size : 20
  - c. Output : KRaster

## 3. Faktor C (pengelolaan dan penutupan lahan)

Faktor pengelolaan dan penutupan lahan dihitung berdasarkan tata guna lahan. Peta tata guna lahan yang digunakan diperoleh dari BAKOSURTANAL berupa peta digital Rupa Bumi Indonesia skala 1 : 25.000. Update tata guna lahan dilakukan berdasarkan survei lapangan yang dilakukan.




Gambar 2.3. Model faktor C

Untuk faktor C, tool yang digunakan adalah :

- Feature to Raster (Featue to Raster C)
  - a. Input : Landuse2005
  - b. Variable
    - Field : KODE_UNSUR
    - Output cell size : 20
  - c. Output : C1

- Reclassify (Reclassify C)
  Tool Reclassify digunakan untuk memasukkan besarnya nilai faktor pengelolaan dan penutupan lahan ke dalam atribut peta. Tool ini tidak bisa memasukkan bilangan dalam bentuk pecahan. Karena itu, nilai C yang dimasukkan berskala antara 0-100, tidak antara 0-1.
  - a. Input : C1
  - b. Variable
    - Reclass field : Value
    - Reclassification :

| Old values | Nama unsur | New Values |
|---|---|---|
| 1214 | Bangunan/Gedung | 10 |
| 1224 | Pemukiman | 10 |
| 5214 | Sawah | 5 |
| 5224 | Sawah tadah hujan | 5 |
| 5234 | Tegalan/Ladang | 60 |
| 5244 | Padang rumput | 2 |
| 5254 | Perkebunan/Kebun | 30 |
| 5264 | Semak belukar | 2 |
| 5274 | Hutan | 1 |

| Old values | Nama unsur | New Values |
|---|---|---|
| 5294 | Bukit batuan | 100 |
| 6264 | Air tawar sungai | 0 |
| 6314 | Air rawa | 0 |
| NoData | | NoData |

c. Output : C2

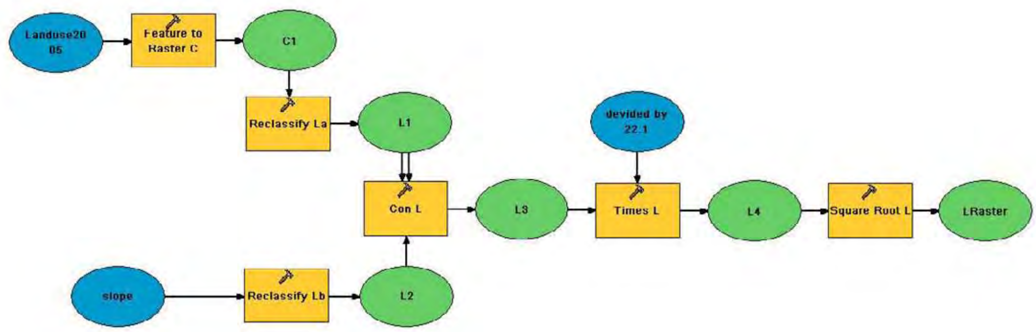
- Times (Times C)
  Tool Times digunakan untuk mengubah nilai C dari skala 0-100 menjadi 0-1. Selain tool Times, bisa juga digunakan tool Divide (dengan constant value 100).
  a. Input : C2
  b. Variable
     - Constant value : 0.01
  c. Output : CRaster

## 4. Faktor L (panjang lereng)

Faktor L tergantung pada tata guna lahan dan kemiringan lereng. Sebagai data input tata guna lahan diambil dari C1 (faktor C) dan data kemiringan lereng (slope). Data kemiringan lereng dibangkitkan dari peta topografi (Peta Rupa Bumi Indonesia skala 1 : 25.000) berupa peta kontur dengan menggunakan tool Topo to Raster. Rumus dari faktor panjang lereng adalah

$$L = \sqrt{\lambda / 22.1}$$

dengan λ adalah panjang lereng.




Gambar 2.4. Model faktor L

Untuk faktor L, tool yang digunakan adalah :

- Reclassify (Reclassify La)
  a. Input : C1
  b. Variable
     - Reclass field : Value
     - Reclassification :

| Old values | Nama unsur | New Values |
|---|---|---|
| 1214 | Bangunan/Gedung | 50 |
| 1224 | Pemukiman | 50 |
| 5214 | Sawah | 1 |
| 5224 | Sawah tadah hujan | 1 |
| 5234 | Tegalan/Ladang | 1 |
| 5244 | Padang rumput | 50 |

| Old values | Nama unsur | New Values |
|---|---|---|
| 5254 | Perkebunan/Kebun | 1 |
| 5264 | Semak belukar | 50 |
| 5274 | Hutan | 50 |
| 5294 | Bukit batuan | 50 |
| 6264 | Air tawar sungai | 50 |
| 6314 | Air rawa | 50 |
| NoData | | NoData |

c. Output : L1

- Reclassify (Reclassify Lb)
  a. Input : Slope
  b. Variable
  - Reclass field : Value
  - Reclassification :

| Old values | New values |
|---|---|
| 0-8 | 8 |
| 8-15 | 8 |
| 15-25 | 4 |
| 25-40 | 3 |
| 40-1147.180054 | 2 |
| NoData | NoData |

c. Output : L2

- Con (Con L)
  a. Input : L1
  b. Variable
  - True raster : L1
  - False rater : L2
  - Expression : Value = 1
  c. Output : L3

- Times (Times L)
  Tool Times digunakan untuk membagi λ dengan bilangan 22.1 (dikalikan dengan 0.045249). Selain tool Times, bisa juga digunakan tool Divide (dengan constant value 22.1).
  a. Input : L3
  b. Variable
  - Constant value : 0.045249
  c. Output : L4

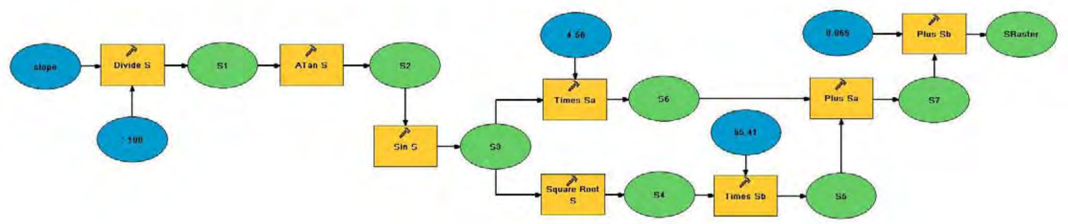
- Square Root (Square Root L)
  a. Input : L4
  b. Output : LRaster

## 5. Faktor S (kemiringan lereng)

Faktor S dihitung dari data kemiringan lereng (slope) dengan rumus

$$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$$

dengan θ adalah tingkat kemiringan lereng. Data kemiringan lereng yang dibangkitkan dalam satuan persen (percent rise).




Gambar 2.5. Model faktor S

Untuk faktor S, tool yang digunakan adalah :

- Divide (Divide S)
  Tool divide digunakan untuk mengubah data slope dari harga persen menjadi harga tangen dari data tersebut dengan cara dibagi 100.
  a. Input : Slope
  b. Variable
     - Constant value : 100
  c. Output : S1

- ATan (Atan S)
  a. Input : S1
  b. Output : S2

- Sin (Sin S)
  a. Input : S2
  b. Output : S3

- Square (Square Root S)
  a. Input : S3
  c. Output : S4

- Times (Times Sb)
  a. Input : S4
  b. Variable
     - Constant value : 65.41
  c. Output : S5

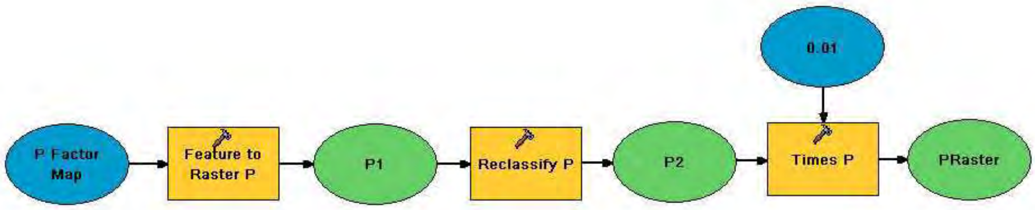
- Times (Times Sa)
  a. Input : S3
  b. Variable
     - Constant value : 4.56
  c. Output : S6

- Plus (Plus Sa)
  a. Input 1 : S5
  b. Input 2 : S6
  c. Output : S7

- Plus (Plus Sb)
  a. Input : S7
  b. Variable
     - Constant value : 0.065
  c. Output : SRaster

## 6. Faktor P (pendukung bercocok tanam)

Faktor pendukung bercocok tanam dihitung berdasarkan praktek pengendalian erosi yang dilakukan para petani pada lahan mereka. Faktor ini dihitung dari peta kondisi teras yang dibuat/diturunkan dari peta tata guna lahan berdasarkan data survei lapangan yang dilakukan untuk mengklasifikasikan praktek pengendalian erosi yang dilakukan.




Gambar 2.6. Model faktor P

Untuk faktor P, tool yang digunakan adalah :

- Feature to Raster (Featue to Raster P)
  a. Input : P Factor Map
  b. Variable
     - Field : Terrace_co
     - Output cell size : 20
  c. Output : P1

- Reclassify (Reclassify P)
  Tool Reclassify digunakan untuk memasukkan besarnya nilai faktor pendukung bercocok tanam ke dalam atribut peta. Tool ini tidak bisa memasukkan bilangan dalam bentuk pecahan. Karena itu, nilai P yang dimasukkan berskala antara 0-100, tidak antara 0-1.
  a. Input : P1
  b. Variable
     - Reclass field : Terrace_co
     - Reclassification :

| Old values | New values |
|---|---|
| Air tawar sungai | 100 |
| Bangunan/Gedung | 100 |
| Bukit Batuan | 100 |
| Hutan | 100 |
| Padang Rumput | 100 |
| Pemukiman | 100 |
| Medium bench terrace | 20 |
| Fair to bad bench terrace | 40 |
| Perkebunan/Kebun | 40 |
| Sawah | 2 |
| Sawah Tadah Hujan | 2 |

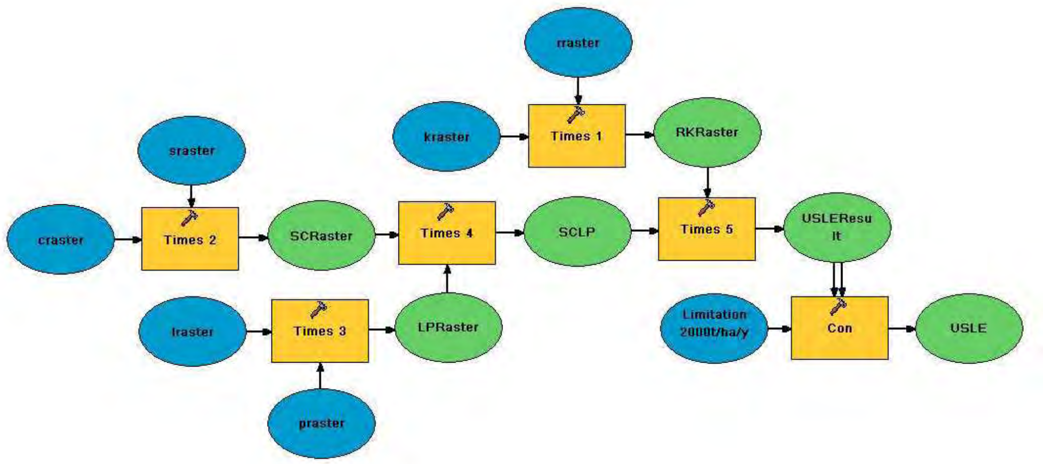
| Old values | New values |
|---|---|
| Semak Belukar | 100 |
| Good bench terrace | 4 |
| Traditional bench terrace | 50 |
| Composite bench terrace | 80 |
| No treatment of soil conservation | 80 |
| Ridge terrace | 80 |
| NoData | NoData |

c. Output : P2

- Times (Times P)
  Tool Times digunakan untuk mengubah nilai C dari skala 0-100 menjadi 0-1. Selain tool Times, bisa juga digunakan tool Divide (dengan constant value 100).
  a. Input : P2
  b. Variable
     - Constant value : 0.01
  c. Output : PRaster

## 7. Menghitung besar rata-rata kehilangan tanah tahunan.

Setelah masing-masing faktor selesai dimodelkan dan dihitung, besarnya rata-rata kehilangan tanah bisa dihitung. Masing-masing faktor tersebut dikalikan sehingga bisa diperoleh besarnya rata-rata kehilangan tanah tahunan dengan satuan ton/hektar/tahun dalam bentu data raster.




Gambar 2.7. Model perhitungan rata-rata kehilangan tanah tahunan.

- Times (Times 1)
  a. Input 1 : rraster
  b. Input 2 : kraster
  c. Output : RKRaster

- Times (Times 2)
  a. Input 1 : sraster
  b. Input 2 : craster
  c. Output : SCRaster

- Times (Times 3)

a. Input 1 : lraster
b. Input 2 : praster
c. Output : LPRaster

- Times (Times 4)
  a. Input 1 : SCRaster
  b. Input 2 : LPRaster
  c. Output : SCLP

- Times (Times 5)
  a. Input 1 : RKRaster
  b. Input 2 : SCLP
  c. Output : USLEResult

# Bab III
# Tabulasi data

Pada bab ini akan dijelaskan mengenai cara mengolah data raster yang dihasilkan menjadi tabel yang mudah dibaca dan dimengerti.

Hasil akhir dari proses pemodelan ini adalah satu set data raster yang bisa diolah untuk ditampilkan atau dicetak dengan menggunakan ArcMap. Data raster tersebut dapat dengan mudah untuk dipahami secara visual, akan tetapi sulit untuk dipahami secara kwantitas/jumlah sehingga perlu untuk diolah sehingga dapat ditampilkan ke dalam bentuk tabel.

Dalam ArcToolbox, ada beberapa tool yang bisa digunakan untuk menghitung statistik dari sebuah raster dan menampilkannya ke dalam bentuk tabel. Hasil dari tool-tool tersebut berupa tabel dalam format .dbf (data base file). Tabel tersebut bisa dibuka dengan program pengolah spreadsheet seperti Microsoft Excel, akan tetapi data yang ada akan sulit dimengerti. Tabulasi data diperlukan untuk menyajikan data dari hasil perhitungan Model Builder ke dalam bentuk tabel dan mengolahnya sehingga dapat dengan mudah dipahami.

## 1. Pengelompokan wilayah (zoning area)

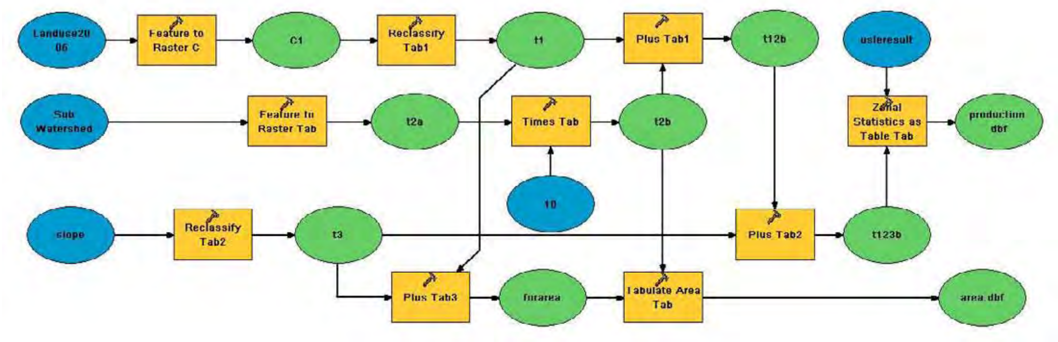
Pengelompokan wilayah (zoning area) digunakan untuk menghitung nilai-nilai statistik dari hasil perhitungan USLE (rata-rata kehilangan tanah tahunan) dari masing-masing wilayah yang telah kita definisikan sebelumnya.

Pengelompokan/klasifikasi bisa dilakukan menurut tata guna lahan, tingkat kemiringan lahan, tingkat produksi erosi, batas wilayah administrasi (desa atau kecamatan), batas sub daerah aliran sungai dan masih banyak lagi. Masing-masing pengelompokan tersebut disimbolkan dalam satu atau lebih digit bilangan tertentu. Dengan cara tersebut, pengelompokan wilayah bisa dilakukan secara sendiri-sendiri atau secara gabungan dari beberapa klasifikasi.

Model berikut ini digunakan untuk pengelompokkan hasil dari perhitungan erosi berdasarkan kombinasi dari :

a. Klasifikasi tata guna lahan, digunakan sebagai digit pertama/ratusan
b. Klasifikasi sub daerah aliran sungai, digunakan sebagai digit kedua/puluhan
c. Klasifikasi tingkat kemiringan lahan, digunakan sebagai digit ketiga/satuan

| **Klasifikasi T.G. lahan** | | **Klasifikasi Sub-DAS** | | **Klasifikasi Slope** | |
|---|---|---|---|---|---|
| **T.G. lahan** | **Kelas** | **Sub-DAS** | **Kelas** | **Slope** | **Kelas** |
| Sawah | 100 | Keduang | 10 | < 8% | 1 |
| Pemukiman | 200 | Tirtomoyo | 20 | 8% - 15% | 2 |
| Tegalan | 300 | Temon | 30 | 15% - 25% | 3 |
| Hutan | 400 | Upper Solo | 40 | 25% - 40% | 4 |
| Perkebunan | 500 | Alang | 50 | > 40% | 5 |
| Lainnya | 600 | Ngunggahan | 60 | | |
| | | Wuryantoro | 70 | | |
| | | Remnant | 80 | | |




Gambar 3.1. Model untuk pengelompokan wilayah.

Tool yang digunakan untuk pengelompokan wilayah antara lain :

- Feature to Raster (Feature to Raster C)
  Jika keseluruhan model digabung menadi satu, tool ini bisa diambil dari model faktor C.
  a. Input : Landuse2005
  b. Variable
     - Field : KODE_UNSUR
     - Output cell size : 20
  c. Output : C1

- Reclassify (Reclassify Tab1)
  Tool Reclassify digunakan untuk memasukkan kode dari klasifikasi lahan sesuai dengan klasifikasi yang kita inginkan (digit pertama/ratusan).
  a. Input : C1
  b. Variable
     - Reclass field : Value
     - Reclassification :

| Old values | Nama unsur | New Values |
|---|---|---|
| 1214 | Bangunan/Gedung | 200 |
| 1224 | Pemukiman | 200 |
| 5214 | Sawah | 100 |
| 5224 | Sawah tadah hujan | 100 |
| 5234 | Tegalan/Ladang | 300 |
| 5244 | Padang rumput | 600 |
| 5254 | Perkebunan/Kebun | 400 |
| 5264 | Semak belukar | 600 |
| 5274 | Hutan | 500 |
| 5294 | Bukit batuan | 600 |
| 6264 | Air tawar sungai | 600 |
| 6314 | Air rawa | 600 |
| NoData | | NoData |

  c. Output : t1

- Feature to Raster (Feature to Raster Tab)
  Klasifikasi sub daerah aliran sungai sudah dimasukkan dalam bentuk kode ke dalam field Id. Untuk mengubah sesuai dengan klasifikasi yang kita inginkan, Id tersebut kita kalikan 10 (menggunakan tool Times) agar menjadi digit kedua/puluhan.

a. Input : Sub Watershed
b. Variable
- Field : Id
- Output cell size : 20
c. Output : t2a

- Times (Times Tab)
a. Input : t2a
b. Variable
- Constant value : 10
c. Output : t2b

- Plus (Plus Tab1)
a. Input 1 : t1
b. Input 2 : t2b
c. Output : plus12b

- Reclassify (Reclassify Tab2)
Tool Reclassify digunakan untuk memasukkan kode dari klasifikasi kemiringan lahan sesuai dengan klasifikasi yang kita inginkan (digit ketiga/satuan).
a. Input : slope
b. Variable
- Reclass field : Value
- Reclassification :

| **Old values** | **New values** |
|---|---|
| 0-8 | 1 |
| 8-15 | 2 |
| 15-25 | 3 |
| 25-40 | 4 |
| 40-1147.180054 | 5 |
| NoData | NoData |

c. Output : t3

- Plus (Plus Tab2)
a. Input 1 : t12b
b. Input 2 : t3
c. Output : t123b

- Plus (Plus Tab3)
a. Input 1 : t1
b. Input 2 : t3
c. Output : forarea

## 2. Penghitungan statistik

Statistik dihitung dengan menggunakan wilayah yang sudah dikelompokkan sebelumnya (zoning area).

- Zoning Statistics as Table (Zonal Statistics as Table Tab)
a. Input zone data : plust2
b. Input value raster : usleresult
c. Variable
- Zone field : value

d. Output : production.dbf

- Tabulate Area (Tabulate Area Tab)
  a. Input zone data : forarea
  b. Input class data : t2b
  c. Variable
     - Zone field : value
     - Class field : value
     - Processing cell size : 20
  d. Output : area.dbf

## 3. Pengolahan file dbf

Hasil data keluaran dari penghitungan statistik (Tool Zoning Statistics as Table dan tool Tabulate Area) adalah berupa file dbf (data base file). File ini bisa dibuka dengan menggunakan program pengolah spreadsheet yang biasa digunakan seperti Microsoft Excel, akan tetapi data tersebut akan sulit dibaca dan dimengerti oleh orang lain. Agar orang lain bisa membaca dan mengerti, perlu pengolahan lebih lanjut file dbf tersebut.

a. Membaca data keluaran

Jika file production.dbf dibuka, besar produksi sedimen bisa dihitung dengan mengkalikan area (meter persegi) dengan mean (ton/hektar) dibagi 10.000.000 untuk mengubah satuan menjadi ribuan ton. Value yang dihasilkan adalah kombinasi 3 angka dari klasifikasi yang sudah kita tentukan yaitu ratusan untuk landuse, puluhan untuk daerah aliran sungai dan satuan untuk tingkat kemiringan lahan. Misalkan value yang dihasilkan adalah 111, maka cara membacanya adalah 100 (sawah) + 10 (Keduang) + 1 (slope kurang dari 8%) = sawah yang terletak di Keduang dengan slope kurang dari 8%.

| **Tata Guna Lahan** | **Slope (%)** | **Sub Daerah Aliran Sungai** | | | **Jumlah** |
|---|---|---|---|---|---|
| | | **Keduang (10)** | **Tirtomoyo (20)** | **Temon (30)** | |
| Sawah (100) | < 8 (1) | 111 | 121 | … | … |
| | 8 – 15 (2) | 112 | 122 | … | … |
| | 15 – 25 (3) | 113 | 123 | … | … |
| | 25 – 40 (4) | 114 | … | … | … |
| | > 40 (5) | 115 | … | … | … |
| Sub-Total | | … | … | … | … |

Gambar 3.2. Penerjemaahan kode klasifikasi

Untuk data area.dbf, data yang tersaji sudah dalam bentuk matrik sehingga bisa langsung dibaca dalam satuan meter persegi. Untuk menyajikan dalam satuan hektare, cukup dengan membaginya 10.000.

b. Menghubungkan file dbf dengan tampilan muka tabel

Agar mudah dibaca, buat tabel yang mudah dimengerti seperti gambar 3.2. Salin data dbf ke salah satu tab pada tabel yang sudah dipersiapkan dan hubungkan.

# *Attachment 3*

# *Presentation Material Prepared by Trainees on the outcome of GIS Training Seminar*

*This presentation material was used in the 4th day of second GIS training seminar for explanation about their activities and outcomes to the persons who did not participated in the training seminar.*

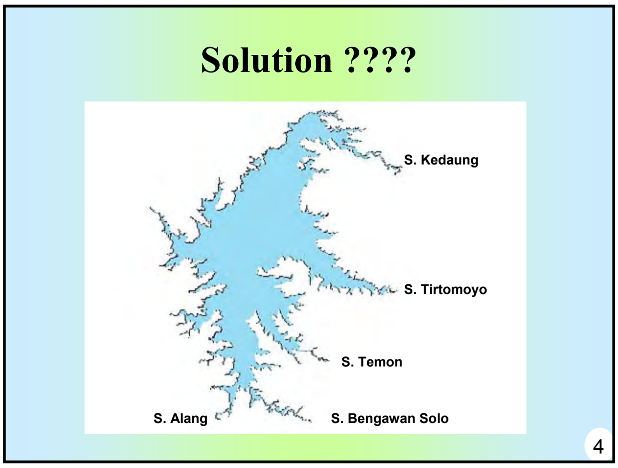
*The contents are as follows:*

- *How to calculate sedimentation volume in Wonogiri reservoir: 3 pages*
- *How to calculate sediment yield in Wonogiri watershed: 3 pages*

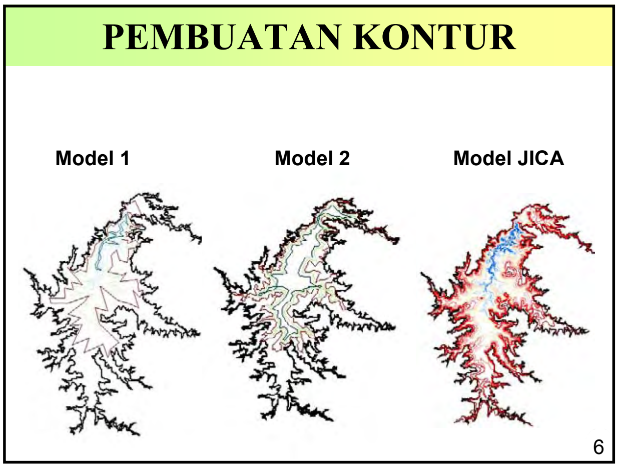

PELATIHAN Arc GIS 9
11 – 15 DESEMBER 2006
LAB. JTS FT UNS
Kelompok 1
MENGHITUNG SEDIMEN WADUK WONOGIRI
1


LATAR BELAKANG
Sedimentasi Waduk Wonogiri
Erosi Permukaan Daerah Tangkapan Air
Pengelolaan Daerah Tangkapan Air
2

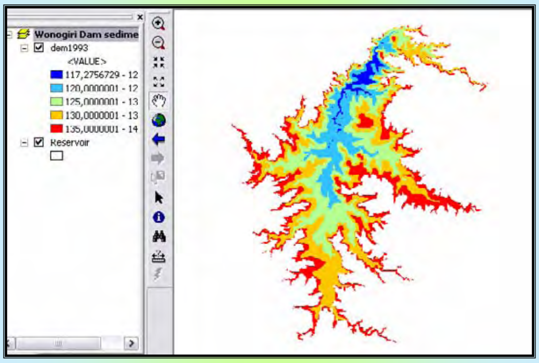

TUJUAN
Volume Erosi Permukaan Daerah Tangkapan Air
Volume Sedimentasi Waduk Wonogiri
3


Solution ????
S. Kedaung
S. Tirtomoyo
S. Temon
S. Alang
S. Bengawan Solo
4


LANGKAH PEMBUATAN PETA SEDIMENTASI DAN VOLUME SEDIMEN WADUK WONOGIRI
1. Data asli hasil pemeruman dasar waduk
2. Transformasi koordinat lokal ke UTM
3. Simpan dengan format DBF 4
4. Tampilkan dalam peta ArcMap
5. Export titik pemeruman ke format shape file
6. Gambar garis kontur tipe polyline
7. Pembuatan DEM (10m x 10m)
8. Kerjakan langkah 1-7 untuk 1993 dan 2005
9. Hitung selisih volume DEM dari langkah 8.
10. Peta sedimentasi, dokumen & laporan.
5


PEMBUATAN KONTUR
Model 1
Model 2
Model JICA
6

## DEM 1993 -JICA

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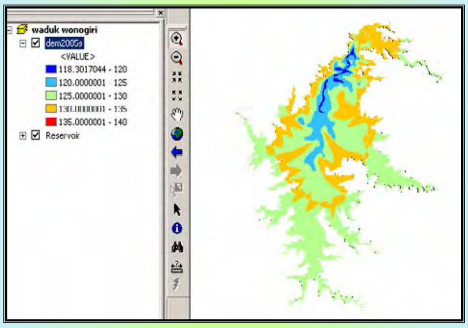
## DEM 2005 – MODEL 1

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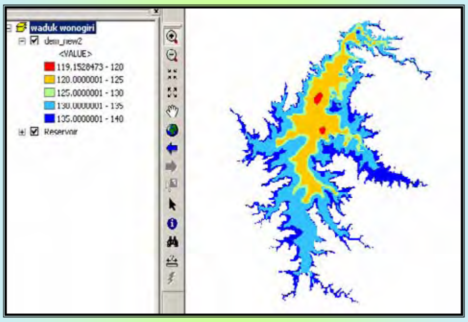
## DEM 2005 – MODEL 2

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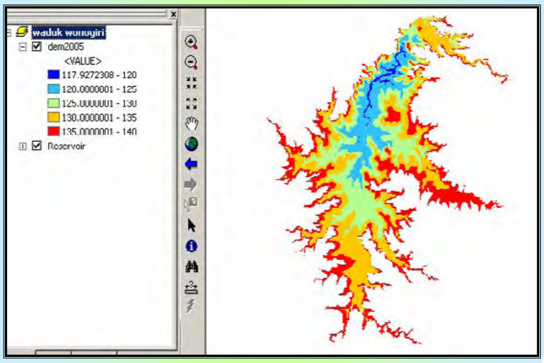
## DEM 2005 - JICA

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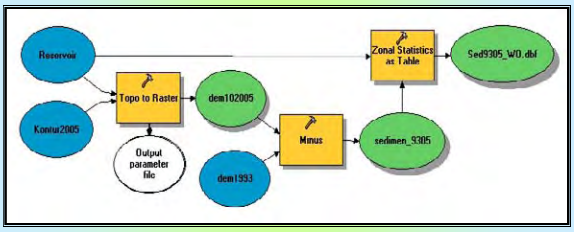
## Perhitungan Sedimentasi Waduk – Model Builder

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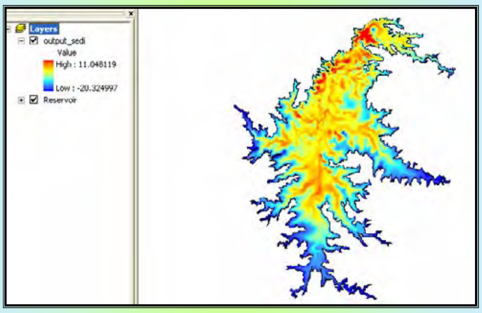
## Sedimentation : Model 1

**(Vol Sedimen= -19.970.083 m3/thn) ???**

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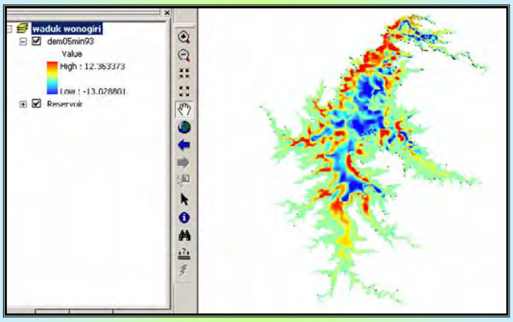
## Sedimentation : Model 2

**(Vol Sedimen= 2.775.900 m3/thn)**

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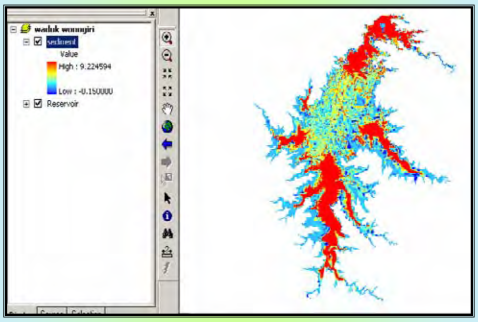
## Sedimentation : JICA

**(Vol Sedimen= 2.885.183 m3/thn)**

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## Kesimpulan

1. Dalam Pemodelan & Simulasi Perhitungan Sedimentasi Didalam Waduk, diperlukan Keterampilan/Ketelitian dari User, Sofware, Hardware yang dipergunakan, Serta Keakuratan Data yang Tersedia
2. Guna Pengelolaan Waduk Jangka Panjang, Penggunaan Sofware Arc. Gis sangat membantu dalam Penetapan Pedoman & Kebijakan yang akan ditetapkan.

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## OLEH-2 & KESAN DARI Arc GIS 9

- Data Base Lengkap & Akurat
- Tampilan Representatif
- Penyajian Hasil Analisa Cepat
- Perlu SDM & Peralatan Yang Memadai
- Pemanfaatan Bidang Lain Lebih Komplek

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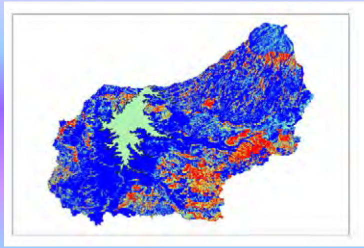
17

*Hasil Training*

*Perhitungan Sedimen Wd. Wonogiri dengan GIS*

*USLE (Universal Soil Loss Equation)*



Kenthingan, 11 s/d 15 Desember 2006

1

*Kegunaan :*

- Menganalisa hasil produksi sedimen yang terakumulasi pada waduk dengan mengolah data spasial dalam sebuah Sistem Informasi Geografis.
- Analisa dengan cara pemrograman visual interaktif menggunakan Model Builder.

2

## *Langkah-langkah Analysis*

3

## *Langkah-langkah Analysis*

- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)

4

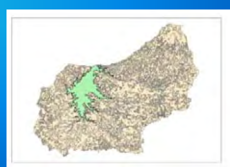
## *Langkah-langkah Analysis*

- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)
  2. Faktor K (erodibilitas tanah)

5

## *Langkah-langkah Analysis*

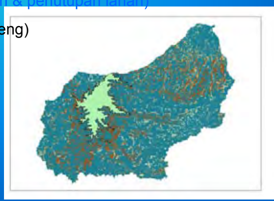
- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)
  2. Faktor K (erodibilitas tanah)
  3. Faktor C (pengelolaan & penutupan lahan)



6

## *Langkah-langkah Analysis*

- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)
  2. Faktor K (erodibilitas tanah)
  3. Faktor C (pengelolaan & penutupan lahan)
  4. Faktor L (panjang lereng)



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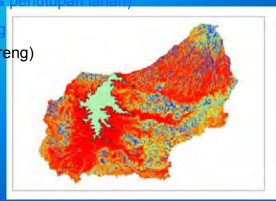
## *Langkah-langkah Analysis*

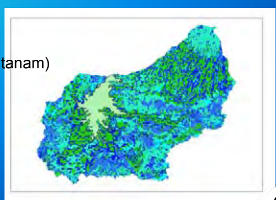
- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)
  2. Faktor K (erodibilitas tanah)
  3. Faktor C (pengelolaan & penutupan lahan)
  4. Faktor L (panjang lereng
  5. Faktor S (kemiringan lereng)



8

## *Langkah-langkah Analysis*

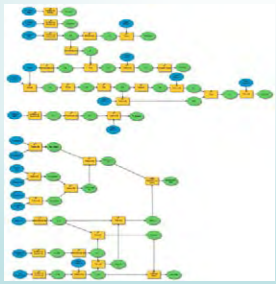
- Penyiapan data-data antara lain :
  1. Faktor R (erosivitas curah hujan)
  2. Faktor K (erodibilitas tanah)
  3. Faktor C (pengelolaan & penutupan lahan)
  4. Faktor L (panjang lereng
  5. Faktor S (kemiringan lereng)
  6. Faktor P (pendukung bercocok tanam)



9

## Menghitung besar rata-rata kehilangan tanah tahunan

- Besar rata-rata kehilangan tanah tahunan dapat dihitung dengan cara membentuk masing-masing faktor menjadi model sehingga didapat nilai besarnya rata-rata kehilangan tanah tahunan dengan satuan yang diinginkan (ton/ha/tahun) dalam bentuk data raster.



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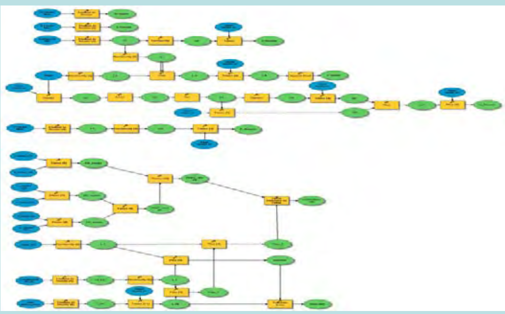
## Model perhitungan besar rata-rata kehilangan tanah tahunan



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## Hasil Akhir

Dari tahapan proses tersebut di atas didapat hasil akhir, berupa :

- Satu set data raster yang dapat dicetak dengan Software ArcMap, yang dapat dipahami secara visual.
- Data dapat ditampilkan kedalam bentuk tabel bilamana diperlukan, dengan cara :
  1. **Pengelompokan Wilayah (Zoning Area)**
     - Klasifikasi tata guna lahan
     - Klasifikasi sub DAS
     - Klasifikasi tingkat kemiringan lahan
  2. **Penghitungan Statistik**
  3. **Pengolahan File database (dbf)**

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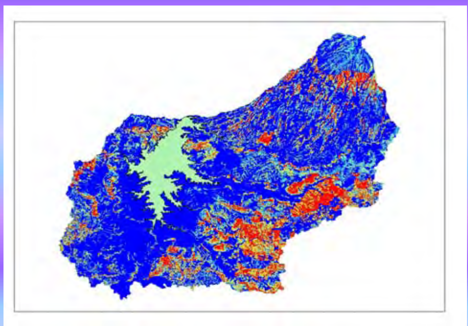
*Hasil Akhir Proses pemodelan dalam bentuk peta raster*



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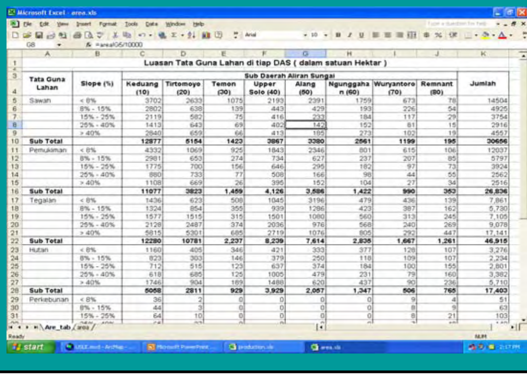
## Tabulasi Data



Luasan Tata Guna Lahan di tiap DAS ( dalam satuan Hektar )

| Tata Guna Lahan | Slope (%) | Keduang (10) | Tirtomoyo (20) | Temon (30) | Upper Solo (40) | Alang (50) | Ngunggahan (60) | Wuryantoro (70) | Remnant (80) | Jumlah |
|---|---|---|---|---|---|---|---|---|---|---|
| Sawah | < 8% | 3702 | 2633 | 1075 | 2193 | 2391 | 1759 | 673 | 78 | 14504 |
| | 8% - 15% | 2802 | 638 | 139 | 443 | 429 | 193 | 226 | 54 | 4925 |
| | 15% - 25% | 2119 | 582 | 75 | 416 | 233 | 184 | 117 | 29 | 3754 |
| | 25% - 40% | 1413 | 643 | 69 | 402 | 142 | 152 | 81 | 15 | 2916 |
| | > 40% | 2840 | 659 | 66 | 413 | 185 | 273 | 102 | 19 | 4557 |
| **Sub Total** | | **12877** | **5154** | **1423** | **3867** | **3380** | **2561** | **1199** | **195** | **30656** |
| Pemukiman | < 8% | 4332 | 1069 | 925 | 1843 | 2346 | 801 | 615 | 106 | 12037 |
| | 8% - 15% | 2981 | 653 | 274 | 734 | 627 | 237 | 207 | 85 | 5797 |
| | 15% - 25% | 1775 | 700 | 156 | 646 | 295 | 182 | 97 | 73 | 3924 |
| | 25% - 40% | 880 | 733 | 77 | 508 | 166 | 98 | 44 | 55 | 2562 |
| | > 40% | 1108 | 669 | 26 | 395 | 152 | 104 | 27 | 34 | 2516 |
| **Sub Total** | | **11077** | **3823** | **1,459** | **4,126** | **3,586** | **1,422** | **990** | **353** | **26,836** |
| Tegalan | < 8% | 1436 | 623 | 508 | 1045 | 3196 | 479 | 436 | 139 | 7,861 |
| | 8% - 15% | 1324 | 854 | 355 | 939 | 1286 | 423 | 387 | 162 | 5,730 |
| | 15% - 25% | 1577 | 1515 | 315 | 1501 | 1080 | 560 | 313 | 245 | 7,105 |
| | 25% - 40% | 2128 | 2487 | 374 | 2036 | 976 | 568 | 240 | 269 | 9,078 |
| | > 40% | 5815 | 5301 | 685 | 2719 | 1076 | 805 | 292 | 447 | 17,141 |
| **Sub Total** | | **12280** | **10781** | **2,237** | **8,239** | **7,614** | **2,836** | **1,667** | **1,261** | **46,916** |
| Hutan | < 8% | 1160 | 405 | 346 | 421 | 333 | 377 | 128 | 107 | 3,276 |
| | 8% - 15% | 823 | 303 | 146 | 379 | 250 | 118 | 109 | 107 | 2,234 |
| | 15% - 25% | 712 | 515 | 123 | 637 | 374 | 184 | 100 | 155 | 2,801 |
| | 25% - 40% | 618 | 685 | 125 | 1005 | 479 | 231 | 79 | 160 | 3,382 |
| | > 40% | 1746 | 904 | 189 | 1488 | 620 | 437 | 90 | 236 | 5,710 |
| **Sub Total** | | **5058** | **2811** | **929** | **3,929** | **2,067** | **1,347** | **506** | **765** | **17,403** |
| Perkebunan | < 8% | 36 | 2 | 0 | 0 | 0 | 0 | 9 | 4 | 51 |
| | 8% - 15% | 44 | 3 | 0 | 0 | 0 | 0 | 8 | 9 | 63 |
| | 15% - 25% | 64 | 10 | 0 | 0 | 0 | 0 | 8 | 21 | 103 |

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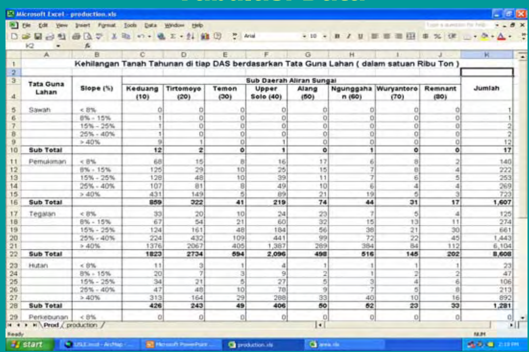
## Tabulasi Data



Kehilangan Tanah Tahunan di tiap DAS berdasarkan Tata Guna Lahan ( dalam satuan Ribu Ton )

| Tata Guna Lahan | Slope (%) | Keduang (10) | Tirtomoyo (20) | Temon (30) | Upper Solo (40) | Alang (50) | Ngunggahan (60) | Wuryantoro (70) | Remnant (80) | Jumlah |
|---|---|---|---|---|---|---|---|---|---|---|
| Sawah | < 8% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 8% - 15% | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 15% - 25% | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 25% - 40% | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | > 40% | 9 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 12 |
| **Sub Total** | | **12** | **2** | **0** | **1** | **0** | **1** | **0** | **0** | **17** |
| Pemukiman | < 8% | 68 | 15 | 8 | 16 | 17 | 6 | 8 | 2 | 140 |
| | 8% - 15% | 125 | 29 | 10 | 25 | 15 | 7 | 8 | 4 | 222 |
| | 15% - 25% | 128 | 48 | 10 | 39 | 11 | 7 | 6 | 5 | 253 |
| | 25% - 40% | 107 | 81 | 8 | 49 | 10 | 6 | 4 | 4 | 269 |
| | > 40% | 431 | 149 | 5 | 89 | 21 | 19 | 5 | 3 | 723 |
| **Sub Total** | | **859** | **322** | **41** | **219** | **74** | **44** | **31** | **17** | **1,607** |
| Tegalan | < 8% | 33 | 20 | 10 | 24 | 23 | 7 | 5 | 4 | 125 |
| | 8% - 15% | 67 | 54 | 21 | 60 | 32 | 15 | 13 | 11 | 274 |
| | 15% - 25% | 124 | 161 | 48 | 184 | 56 | 38 | 21 | 30 | 661 |
| | 25% - 40% | 224 | 432 | 109 | 441 | 99 | 72 | 22 | 45 | 1,443 |
| | > 40% | 1376 | 2067 | 405 | 1,387 | 289 | 384 | 84 | 112 | 6,104 |
| **Sub Total** | | **1823** | **2734** | **594** | **2,096** | **498** | **516** | **145** | **202** | **8,608** |
| Hutan | < 8% | 11 | 3 | 1 | 4 | 1 | 1 | 1 | 1 | 23 |
| | 8% - 15% | 20 | 7 | 3 | 9 | 2 | 1 | 2 | 2 | 47 |
| | 15% - 25% | 34 | 21 | 5 | 27 | 5 | 3 | 4 | 6 | 106 |
| | 25% - 40% | 47 | 48 | 10 | 78 | 9 | 7 | 5 | 8 | 213 |
| | > 40% | 313 | 164 | 29 | 288 | 33 | 40 | 10 | 16 | 892 |
| **Sub Total** | | **426** | **243** | **49** | **406** | **50** | **52** | **23** | **33** | **1,281** |
| Perkebunan | < 8% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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## *Tanggapan kami*

Dengan diadakan Workshop ke II yang merupakan lanjutan dari workshop I yang telah dilaksanakan pada bulan Juli 2006 bertempat di Fak. Teknik UNS, peserta merasa senang karena bertambah pengetahuannya khususnya tentang program GIS serta mengetahui lebih jauh akan perlunya program tersebut untuk dikembangkan serta melanjutkannya dengan memperbaharui (updating) data pendukung, sehingga program ini akan dapat lebih bermanfaat di masa mendatang.

Perlu adanya pengalihan pengetahuan terutama program GIS kepada generasi berikutnya, sehingga informasi yang ada akan selalu bertambah dan mendekati kesempurnaan seperti yang diharapkan.

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## Peserta Group Dua

**Matur nuwun ……** Arigatou gozaimasu

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# *Annex No.15*
# *Dam Safety Analysis*

THE STUDY ON
COUNTERMEASURES FOR SEDIMENTATION
IN
THE WONOGIRI MULTIPURPOSE DAM RESERVOIR
IN
THE REPUBLIC OF INDONESIA

# FINAL REPORT

# SUPPORTING REPORT III

# Annex No.14: Dam Safety Analysis

## Table of Contents

## List of Tables



## List of Figures

# CHAPTER 1 RE-ALLOCATION OF RESERVOIR STORAGE CAPACITY

## 1.1 Introduction

If the Wonogiri reservoir supplies water according to the current operation rule, around 75 million $m^3$ of water supply shall be reduced under the current sedimentation condition in the reservoir. This would cause serious impacts to the stakeholders in the downstream because they are accustomed to the current water use practice, even though the total stored volume in reservoir exceeds the initially allocated storage volume. Further guarantee of current water use might be of strong need for all the stakeholders. Therefore evaluation on re-allocation of current remaining storage capacity as of 2005 was made in order to secure the current water supply from the Wonogiri reservoir.

## 1.2 Review of Reservoir Operation Rules

After the completion of the Wonogiri Dam in 1982, there are three phase for the reservoir operation rule.

(1) First Phase

First phase was establishment of reservoir operation rule by Nippon Koei Co., Ltd. in February 1984. At that time, considering the progress of on-going river improvement projects, the proposed reservoir operation rule was composed of two rules, the provisional one (Operation Rule for First Phase of Wonogiri Dam and Power Station) and the final rule (Manual for Operation and Maintenance for Second Phase of Wonogiri Dam and Power Station). The provisional rule was intended to use from December 1, 1983 until completion of Upper Solo River improvement project. The proposed regulating water levels and allocated storage capacities under the both two rules were as follows:

**Table 1.2.1 Reservoir Operation Rule in 1984**

| Definition | Provisional Rule | Final Ru7le |
|---|---|---|
| 1. Period (Article 3) | | |
| Flood | December 01 to April 15 | December 01 to April 15 |
| Non-flood | May 01 to November 30 | May 01 to November 30 |
| Recovery | April 16 to April 30 | April 16 to April 30 |
| 2. Flood discharge (Article 2) | Inflow discharge exceeding 400 $m^3/s$ | Inflow discharge exceeding 400 $m^3/s$ |
| 3. Water Level in Flood Period (Article 13) | Maintain **EL. 134.5 m**, Flood control capacity of **272** million $m^3$ **(EL. 134.5 m – EL. 138.2m)** | Maintain **EL. 135.3 m**, Flood control capacity of **220** million $m^3$ **(EL. 135.3 m – EL. 138.2m)** |
| 4. Water Level in Non-Flood Period (Article 13) | Draw down of **EL. 127.0 m – EL. 134.5 m**, water use capacity of **343** million $m^3$ | Draw down of **EL. 127.0 m – EL. 136.0 m**, water use capacity of **440** million $m^3$ |

Source: Manual for Operation and Maintenance, February 1984

(2) Second Phase

Second phase was authorization of the Ministerial Decree of Public Works No. 229/KPTS/1986 on Operation and Maintenance Manual of Wonogiri Multi-purpose Dam

(Keputusan Menteri Pekerjaan Umum tentang Pedoman Eksploitasi dan Pemeliharaan Bendungan Serbaguna Wonogiri) in 1986. This authorized operation rule basically adopted the provisional rule proposed in 1984, because the river improvement works on the Upper Solo River had not been initiated (construction period is 1987-1994). In the light of the above, the illustrated monthly reservoir operation rule curve that is attached to the Ministerial Decree No. 229/KPTS/1986 (see Figure 1.2.1) seems incorrect, because the expected reservoir water level at the beginning of the recovery period is above CWL EL. 134.5 m.

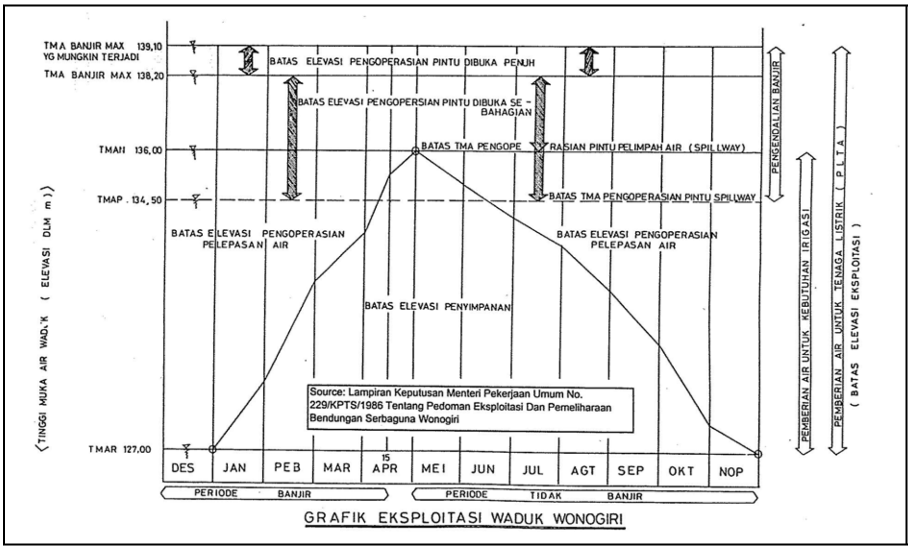



**Figure 1.2.1 Authorized Wonogiri Dam Reservoir Operation Rule in 1986**

(3) Third Phase

Third phase was the modification of original operation rule according to the some report titled by Optimasi Pemanfaatan Air Bendungan Serbaguna Wonogiri, Departmen Pekerjaan Umum Directorat Jenderal Pengairan Proyek Induk Pengembangan Wilayah Sungai Bengawan Solo in November 1993, although the authorization of the modified one remains uncertain. This modification was carried out almost same time of completion of the river improvement works on the Upper Solo River in 1994. The rule modification was made to increase water supply capacity of the Wonogiri reservoir reflecting strong water demand in the dry season for the new irrigation area (Colo Barat Phase II with 2,350 ha). Figure 1.2.2 shows the revised Wonogiri reservoir operation rule in 1993. As seen, main points of the modified operation rule is as follows:

i) The control water level (CWL) is changed EL. 135.3 m from EL. 134.5 m (that was proposed in 1984 as the final reservoir operation rule).
ii) Three operation rule curves were established, the maximum, normal and minimum water level curves.
iii) The minimum operation water level curve is the same as the authorized rule curve in 1986.
iv) Under the normal water level curve, the reservoir water level is above CWL EL. 135.3 m around the end of March during the flood period. This will reduce the flood control capacity in the remaining flood period.
v) Under the maximum operation water level curve, the reservoir water level is above CWL EL. 135.3 m around the end of February during the flood period. This also makes reduce the flood control capacity in the remaining flood period.

It is noted however that the modification of reservoir operation rule in 1993 made the Wonogiri dam dangerous against design flood and PMF because the reservoir water level exceeds CWL EL. 135.3 m during the flood period. The reservoir water level should be controlled so as not to exceed CWL EL. 135.3 m during the flood period for eliminating the possibility for overtopping of the dam.

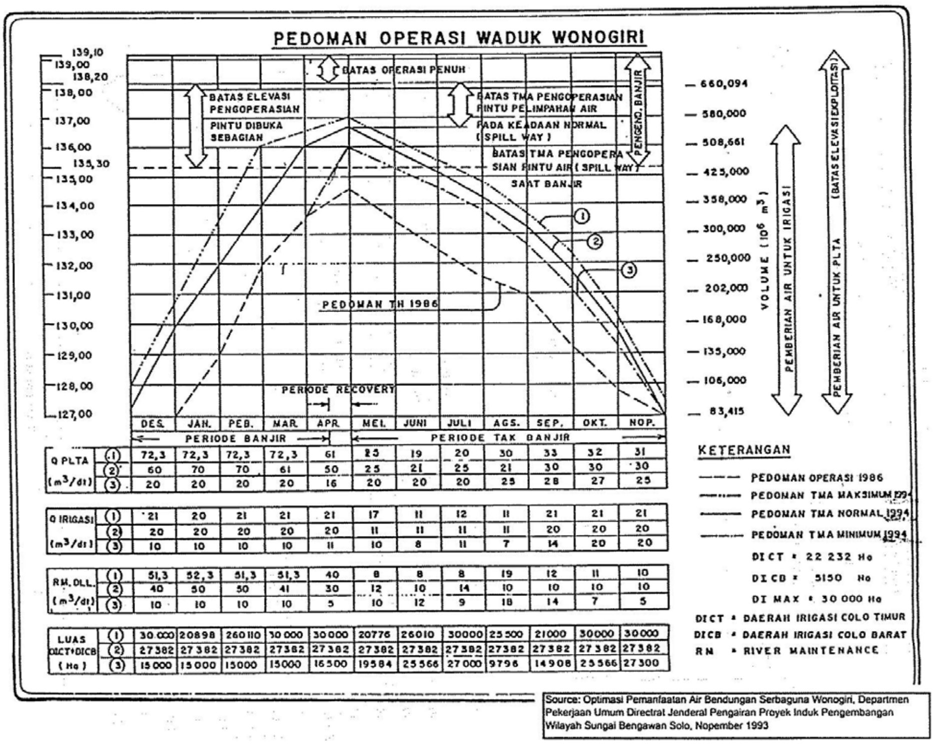



**Figure 1.2.2 Revised Wonogiri Dam Reservoir Operation Rule in 1993**

## 1.3 Review of Basic Concept of Reservoir Operation

### 1.3.1 Design Flood

The inflow discharge exceeding 400 $m^3/s$ is called as a flood in the Wonogiri Dam operation rule. Three design floods had been defined to determine the operating water level and design of spillway and dam main body as shown in the Table 1.3.1 below.

**Table 1.3.1 Design Floods of Wonogiri Dam Reservoir**

| Design Flood | | Peak Inflow Discharge | Remark |
|---|---|---|---|
| Standard Highest Flood Discharge | (SFHD) | 4,000 $m^3/s$ | Project design flood for flood control corresponding to the Recorded maximum flood in 1966 which recurrence interval of 60 years |
| Spillway Design Flood | (Design Flood) | 5,100 $m^3/s$ | 1.2 times of 100-year probable flood |
| Probable Maximum Flood | (PMF) | 9,600 $m^3/s$ | (Extraordinary flood) |

Source: JICA Study Team. Above data is referred to "Wonogiri Multipurpose Dam Project, Part I Summary Report on Detail Engineering Services, January 1978, Nippon Koei Co., Ltd."

### 1.3.2 Flood Control Operation

Flood period and non-flood period are defined as follows:

| | | |
|---|---|---|
| Flood period | : | December 1 to April 15 |
| Non-Flood period | : | May 1 to November 30 |
| Recovery period | : | April 16 to April 30 |

During the flood period, the reservoir water level shall be maintained at EL. 135.30 m, so that the reservoir has a storage capacity of 220 x $10^6$ $m^3$ to control flood discharge.

At the time of the inflow discharge exceeding 400 $m^3$/sec, the discharge releasing from the reservoir shall be made to keep the total outflow discharge at 400 $m^3$/s constantly, allowing the surcharge in the reservoir. This control shall be operated by partial opening of the spillway gates following to the rule, until the reservoir water level reaches to EL. 138.20 m. In case that reservoir water level rises above EL. 138.20 m, the discharge releasing from the spillway shall be made in a manner of free overflow. For which all the spillway gates shall be set at the full open position. No partial operation of the spillway gates shall be allowed, until the reservoir water level lowers to EL. 137.70 m.

**Table 1.3.2 Current Gate Control for Flood Operation**

| Condition | Outflow ($m^3$/s) | Gate Control |
|---|---|---|
| RWL < CWL (EL. 135.3 m) | 0 | No control |
| CWL (EL. 135.3 m) < RWL < SWL (EL. 138.2 m) | 0-400 | Gate control |
| SWL (EL. 138.2 m) ≦ RWL < EFWL(EL. 139.1 m) | 400-1,360 | Free flow |

Source: JICA Study Team

<Spillway Gate>

| | | |
|---|---|---|
| Height of Crest | : | EL. 131.0 m |
| Gate Type | : | Radial Gate |
| Width | : | B = 30 m |
| Nos. | : | 4 nos. (7.5 m) |

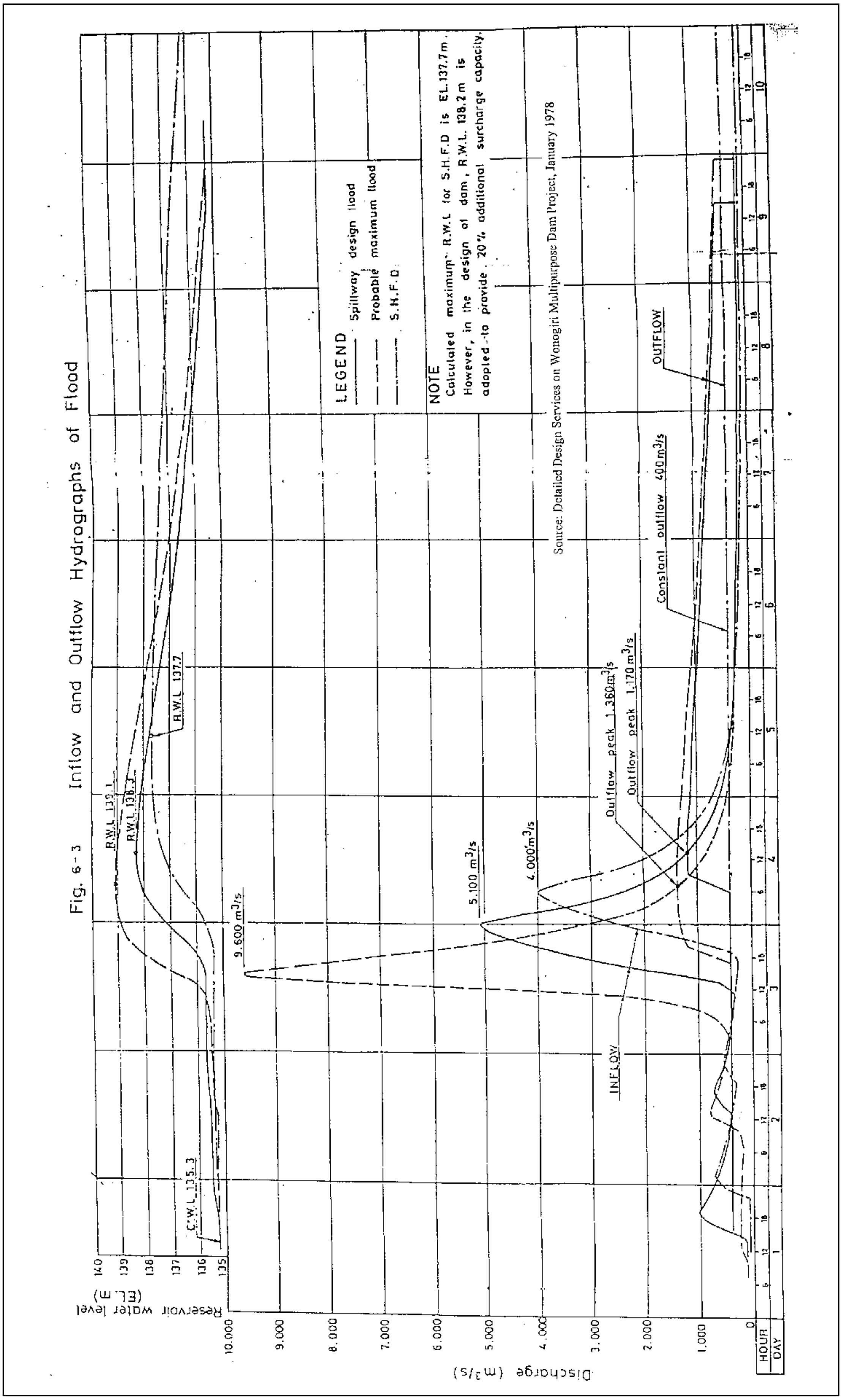
### 1.3.3 Design Water Level

The design water levels of design floods were determined by the flood control simulation based on the stipulated operation rule as mentioned above. Inflow and outflow hydrographs of floods to Wonogiri Reservoir is shown in Figure 1.3.1. Maximums of stored volume, reservoir water level and outflow of design floods are summarized in table below.

**Table 1.3.3 Operation Rule for Flood Control**

| Design Flood | | Peak Inflow Discharge ($m^3$/s) | Maximum Stored Volume (MCM) | Meximum Reservoir Water Level (EL. m) | Maximum Outflow ($m^3$/s) |
|---|---|---|---|---|---|
| Standard Highest Flood Discharge | (SFHD) | 4,000 | 183 | 137.7 | 400 |
| Spillway Design Flood | (Design Flood) | 5,100 | 228 | 138.3 Design Flood Water Level (DFWL) | 1,160 |
| Probable Maximum Flood | (PMF) | 9,600 | 305 | 139.1 Extra Flood Water Level (EFWL) | 1,360 |

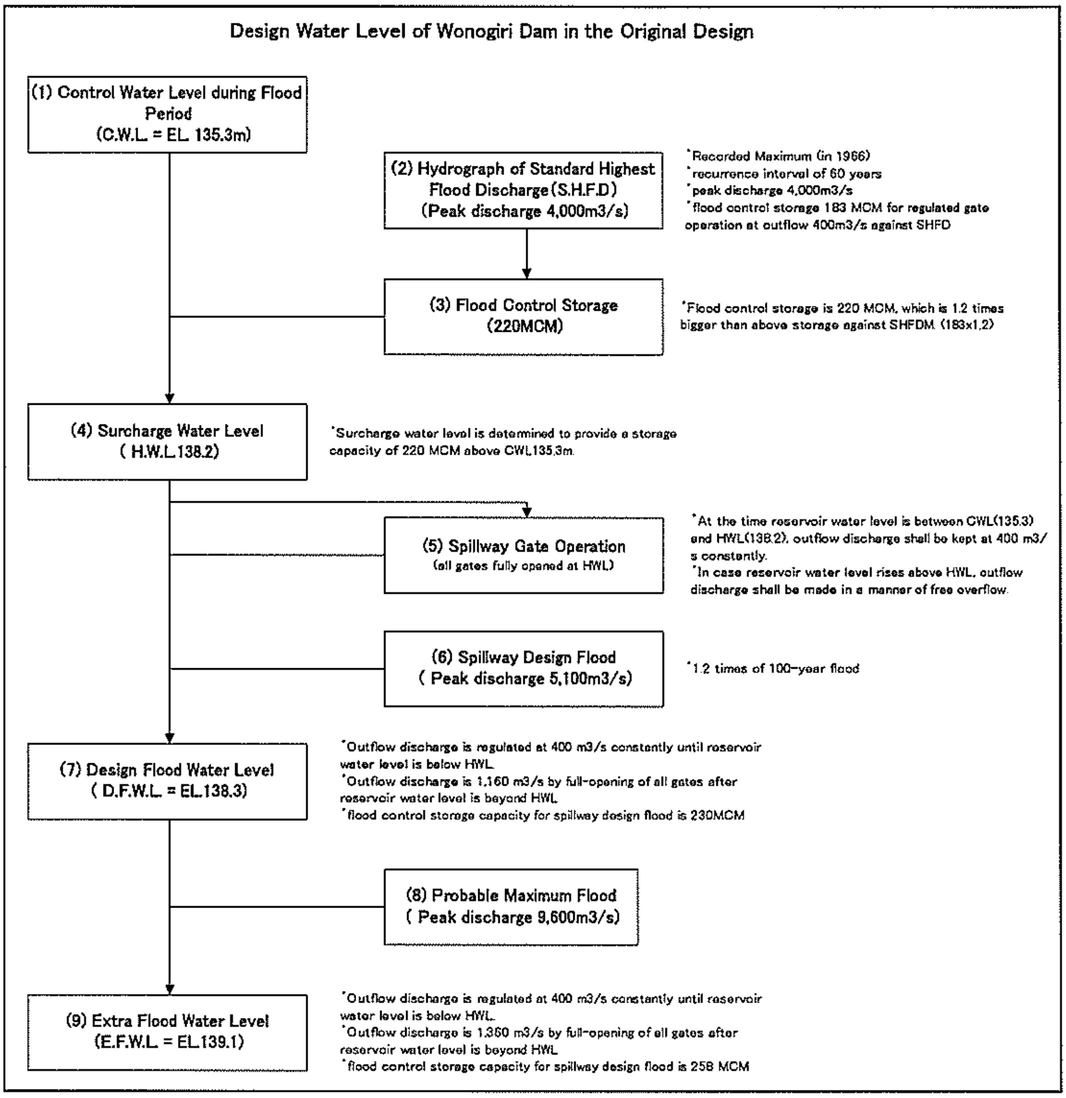
Source: JICA Study Team. Above data is referred to "Wonogiri Multipurpose Dam Project, Part I Summary Report on Detail Engineering Services, January 1978, Nippon Koei Co., Ltd."




Source: Wonogiri Multipurpose Dam Project, Part I Summary Report on Detail Engineering Services, January 1978, Nippon Koei Co., Ltd.

**Figure 1.3.1 Inflow and Outflow Hydrographs of Design Flood**

In addition to design water levels mentioned above, surcharge water level EL. 138.2 m was established to maintain a flood control storage capacity of 220 x $10^6$ $m^3$ which is 1.2 times bigger than the control storage capacity against Standard Highest Flood Discharge (SHFD) of 4,000 $m^3$/s. In case the reservoir water level exceeds the surcharge water level, all spillway gates shall be set at the full open position. Flow chart of establishment of design water level is shown in Figure 1.3.2.




Source: JICA Study Team

**Figure 1.3.2 Flow Chart of Establishment of Design Water Levels**

## 1.4 Review of Freeboard of the Dam

Freeboard is the vertical distance between the top of the impervious core zone of embankment (without camber) and the reservoir water surface. The freeboard provides a safety factor against many contingencies, such as settlement of the dam, occurrence of an inflow flood somewhat larger than the design flood, or malfunction of spillway controls or outlet works etc.

To establish the freeboard and to determine the top elevation of the impervious core zone of the main dam, the following three (3) cases were considered. The criteria of Cases 1 and 2 are given in "Design of Small Dams" and that of Case 3 is given in "Design Criteria for Dams of Japan".

Case 1: PMF occurs and the spillway functions as planed. In this case the freeboard is provided to prevent rising of the water surface over the impervious core zone of the embankment by wave action which may coincide with the occurrence of the probable maximum flood.

Case 2: PMF occurs when the spillway malfunction from human or mechanical failure to open gates. In such instances, allowances for wave action or other contingencies are not made, but the dam should not be overtopped.

Case 3: Design flood occurs when the spillway functions as planed. In this case the freeboard consists of allowance for wave action, malfunction of spillway gates and allowance due to the dam type whether fill type or not. If the half of wave height due to earthquake exceeds the wave height due to wind, the former is adopted instead of the latter.

(1) Case 1

PMF and its highest reservoir water level when the spillway functions as planned are 9,600 $m^3/s$ and RWL EL. 139.10 m respectively. The wave height (Ht) was calculated by the following formula applying the mean wind velocity of 20 m/s and fetch distance of 15,000 m, which gives the highest wave height to the dam embankment due to the longest wave propagation length.

$$Ht = 0.00086 \times V^{1.1} \times F^{0.45}$$
$$= 0.00086 \times 20^{1.1} \times 15{,}000^{0.45}$$
$$= 1.76 \text{ m}$$

Where, Ht : wave height (m)
V : mean wind velocity (m/s)
F : fetch distance (m)

In consequence, the top elevation of the impervious core zone should be higher than:

$$H = EFWL + Ht$$
$$= 139.1 + 1.76$$
$$= \text{EL. } 140.86 \text{ m}$$

Where, H : highest reservoir water level (EL. m)
EFWL : extra flood water level (EL. m)
Ht : wave height (m)

(2) Case 2

The flood volume of PMF is calculated at 473 million $m^3$. If the whole volume of flood is stored in the reservoir as the result of malfunction of the spillway, the reservoir water level will rise to EL. 140.90 m.

In consequence, the top elevation of the impervious core zone should be higher than:

$$H = \text{EL. } 140.90 \text{ m}$$

(3) Case 3

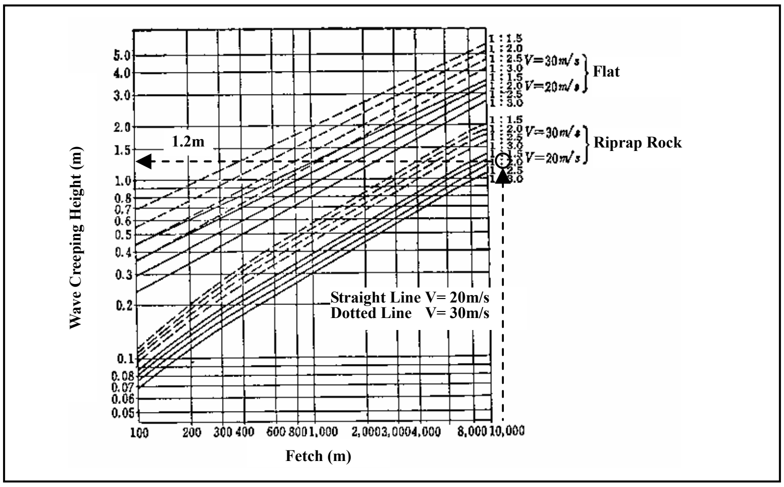
The wave creeping height on the embankment slope due to wind action is calculated by the Savile's method considering the slope of embankment, type of slope protection, wind velocity and fetch as follows;

Type of slope protection Raked-out rock riprap
Slope of embankment 1:3.6

Wind velocity 20 m/s
Fetch distance 15,000 m

The wave creeping height (Ht) is calculated from the figure below.

Ht =1.2 m




Source: Design Criteria for Dams, Japanese National Committee on Large Dams

**Figure 1.4.1 Wave Creeping Height by Savile's Method**

The wave height due to earthquake (He) is calculated from the following formula by Seiichi Sato.

$$
\begin{aligned}
He &= k\tau/\pi\sqrt{gh} \\
&= 0.12 \times 0.1/\pi\sqrt{9.8 \times 28.3} \\
&= 0.064\,\text{m}
\end{aligned}
$$

Where, He : wave height due to earthquake (m)
k : horizontal seismicity (= 0.12)
$\tau$ : period of seismic waves (= 0.1 second)
g : gravity acceleration (= 9.8 m/s$^2$)
h : depth of reservoir water (138.3 – 110.0 = 28.3 m)

The wave height was applied the wave creeping height (Ht) due to wind action because it exceeded the half value of the wave height of the earthquake (He).

Allowance for malfunction of spillway gates (Hg) is usually taken at 0.5 m for gated spillway. Allowance for the dam type (Hd) is usually taken at 1.0 m for earth fill dam.

In consequence, the top elevation of the impervious core zone should be higher than,

H = DFWL + Ht + Hg + Hd
= 138.3 + 1.2 + 0.5 + 1.0
= EL. 141.0 m

Where, H : highest reservoir water level (EL. m)
DFWL : design flood water level (EL. m)
Ht : wave height (m)
Hg : allowance for malfunction of spillway gates
Hd : allowance for the fill dam

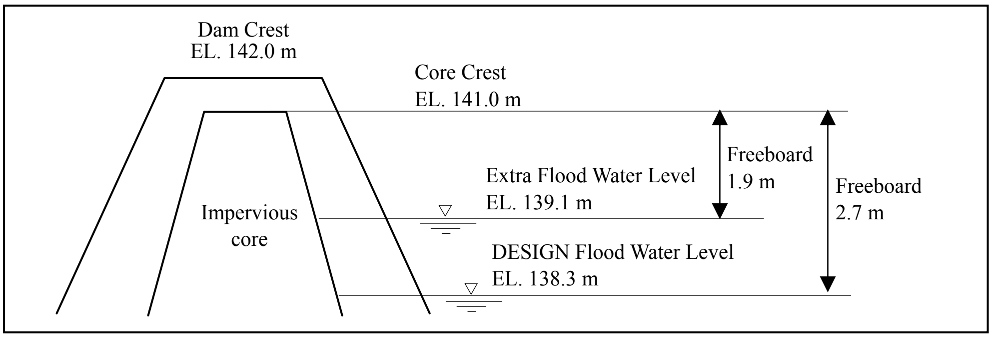
The results of above three cases are summarized below.

**Table 1.4.1 Consideration of Freeboard for Three Cases**

| | Maximum Reservoir Water Level | | Freeboard | | | | | | Necessary top elevation of impervious core zone | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case 1 | EFWL 139.1 | + | wave 1.8 | | | | | = | 140.9 | ≦ EL.141.0m |
| Case 2 | 140.9 | + | 0 | | | | | = | 140.9 | ≦ EL.141.0m |
| Case 3 | DFWL 138.3 | + | wave 1.2 | + | gate 0.5 | + | Earth fill dam 1.0 | = | 141.0 | ≦ EL.141.0m |

Source: JICA Study Team

As a result, the top elevation of impervious core zone was determined EL. 141.0 m as illustrated below. Freeboard is 1.9 m against the extra flood water level EL. 139.1 m and 2.7 m against DFWL of EL. 138.3 m to prevent the reservoir water surface from overtopping the impervious core zone of the embankment.




Source: JICA Study Team

**Figure 1.4.2 Freeboard of Wonogiri Dam**

## 1.5 Conclusion on Possibility of Re-allocation

The Wonogiri reservoir has already lost approximately 49% of the sediment storage capacity and 13% of the effective storage capacity. Conceivable solution to recover the decreased storage capacity is to raise NHWL EL. 136.0 m without decrease the dam safety. In order to secure the dam safety for overtopping, both of extra flood water level and DFWL should not be modified without heightening of the impervious core zone of dam embankment.

If NHWL is raised, it is necessary to raise the CWL or extend the recovering period from April 15 to April 30 so that the reservoir water level can recover to NHWL from CWL during the recovering period.

In case the CWL is raised, both of flood control storage and PMF control storage would be decreased because the DFWL and the extra flood water level cannot be raised. Construction of a new spillway could be one solution against the decreasing of PMF flood control storage by the effect of increasing of the releasing discharge. However, there is a constraint of flood control operation which make to keep the outflow discharge so as not to exceed 400 $m^3/s$ during the inflow discharge is less than Standard Highest Flood Discharge (4,000 $m^3/s$) even though spillway discharge capacity could be increased by new spillway. Because of this constraint due to the flood control operation rule, NHWL can not be raised.

In conclusion, re-allocation of the current remaining storage capacity can not be made without heightening of the dam body. For the extension of recovering period, there is some possibility though it need detail study.

# CHAPTER 2 SEEPAGE THROUGH IMPERVIOUS CORE ZONE

## 2.1 Purpose

As discussed in the Chapter 1 in this Supporting Report, it was concluded that NHWL can not be raised due to the constraint regulated by the flood control operation rule taking into consideration of flood in the downstream of the dam.

This chapter, however, will provide a consideration for raising NHWL with an analysis result obtained by using SEEP/W, which is a finite element software product that can be used to model the movement and pore-water pressure distribution within porous materials such as soil and rock.

The purpose of this analysis is as follows:

1) To review the past seepage calculation[1] carried out manually before the dam construction, and to confirm the dam safety against seepage failure under the condition of the present dam operation rule, which fixes NHWL of EL.136.0 m, by re-calculation using SEEP/W.

2) To prepare flow nets of a few cases of raised NHWL for slope stability analysis, which will be discussed in the next chapter.

## 2.2 Review of the Past Seepage Analysis

According to the report on Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978 (hereinafter called "Design Calculations 1978"), the past seepage analysis for the cofferdam and the main dam has been carried out as follows:

(1) Method

Seepage quantity through the impervious core of the main dam is estimated with the following equation:

$$Q = k y_o L$$

where, Q = seepage quantity

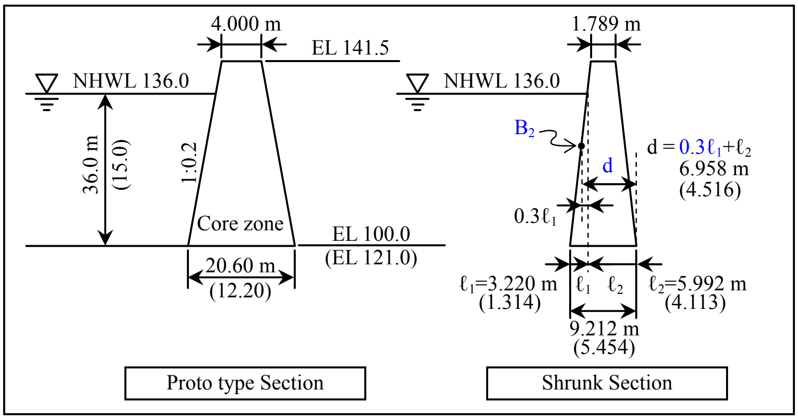
k = horizontal permeability coefficient = $1.0 \times 10^{-6}$ cm/sec

$y_o$ = $\sqrt{h^2 + d^2} - d$

h = head on impervious core zone or water depth in the reservoir

d = length between the downstream toe and $B_2$ point shown in the figure below on the shrunk section of core zone in accordance with a ration of permeability coefficient in vertical and horizontal directions. The ration of permeability coefficient is usually taken as $k_v/k_h$ = 1/5 and the section of impervious zone is horizontally shrunk by $\sqrt{k_v/k_h}$

[1] Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978




Note: Figures without and in parentheses correspond to river portion and right bank respectively.

Source: Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978

L = length of dam

$L_1$ = 360 m in river portion

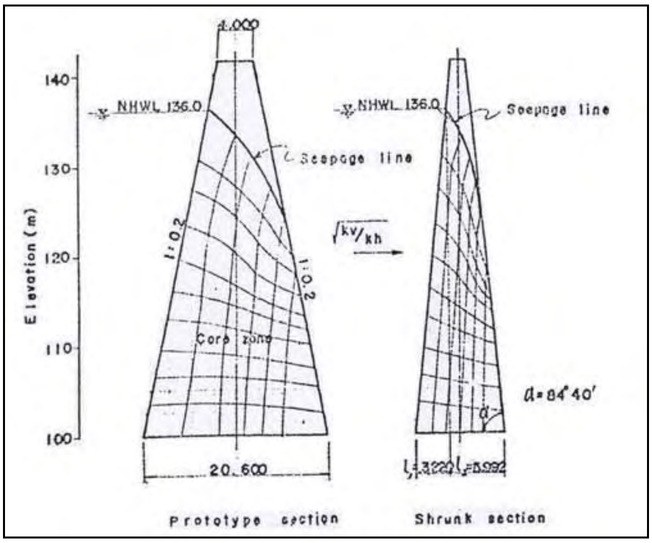
$L_2$ = 460 m in right bank

(2) Estimation

Then the seepage quantity was estimated at about 10 ℓ/min as shown below:

$$Q = 1 \times 10^{-8}\ (m/sec) \times (\sqrt{36.0^2 + 6.958^2} - 6.958) \times 360$$
$$+ 1 \times 10^{-8}\ (m/sec) \times (\sqrt{15.0^2 + 4.516^2} - 4.516) \times 460$$
$$= (1.05 + 0.51) \times 10^{-4}$$
$$= 1.56 \times 10^{-4}\ m^3/sec$$
$$= 9.36\ \ell/min$$

Seepage line was calculated by Casagrande's method. The seepage line and flow net in the core zone estimated in 1978 is shown in Figure 3.2.1.




Source: Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978

**Figure 2.2.1 Seepage Line and Flow Net Estimated in Design Calculations 1978**

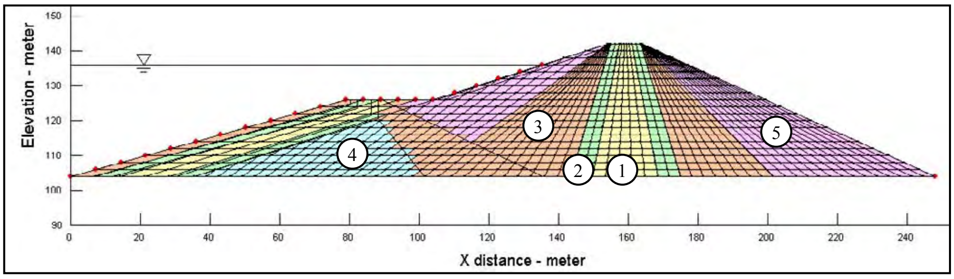
## 2.3 Seepage Analysis by SEEP/W

SEEP/W is one of applications for groundwater seepage analysis by FEM (finite element method), which can be utilized to model distribution of excess pore water pressure and groundwater flow in porous media such as soil and rock.

### 2.3.1 Data Input Condition for Calculation

The condition of the calculation was defined based on the report, Design Calculations 1978, as follows:

i) Analysis type: Steady-state
ii) Control (analysis view): Two-dimensional
iii) Shape of the Dam and its division into elements: As Figure 2.3.1
In this analysis, the same sectional plan as the calculation in 1978 was selected since it is the highest and critical for dam safety.




Source: JICA Study Team

**Figure 2.3.1 Defined Elements of Wonogiri Dam**

iv) Material property: As Table 2.3.1

**Table 2.3.1 Physical and Mechanical Property**

| No. | Material | K-Ratio (kv/kh) | Conductivity |
|---|---|---|---|
| 1 | Core | 1/5 | 1.0 x $10^{-6}$ (cm/sec) |
| 2 | Filter | 1/5* | 2.6 x $10^{-3}$ (cm/sec) |
| 3 | Rock – I | 1/5* | Free drain |
| 4 | Random | 1/5* | 2.6 x $10^{-3}$ (cm/sec) |
| 5 | Rock – II | 1/5* | Free drain |

Notes: K-Ratio: The hydraulic conductivity ration of each material
kv = permeability coefficient in vertical direction
kh = permeability coefficient in horizontal direction
* The same value of K-Ratio No.1 is also applied for No.2-5 since they are not provided in the report.

Source: Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978

v) Boundary condition of water level

The following four cases of water level were examined:

**Table 2.3.2 Four Cases of Water Level to be Examined**

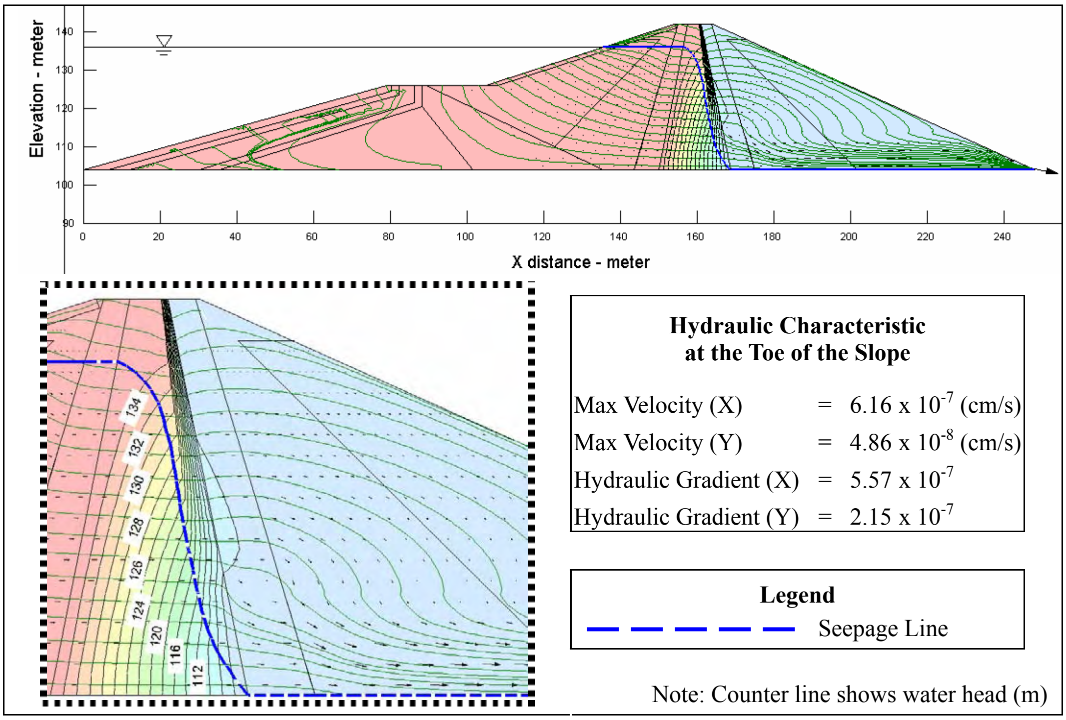
| Case | Upstream side | Downstream side |
|---|---|---|
| Case 1 | EL. 136.0 m (the present NHWL) | EL. 104.0 m (ground level) |
| Case 2 | EL. 137.0 m | EL. 104.0 m (ground level) |
| Case 3 | EL. 138.0 m | EL. 104.0 m (ground level) |
| Case 4 | EL. 139.0 m | EL. 104.0 m (ground level) |

Source 1: Wonogiri Multipurpose Dam Project, Part II Dam and Power Station Volume V-2, Design Calculations for Dam and Spillway, January 1978
Source 2: JICA Study Team

## 2.3.2 Calculation Result

### (1) Case 1: NHWL of EL. 136.0 m

The seepage line and flow line at NHWL of EL. 136.0 m is shown in the figure below:

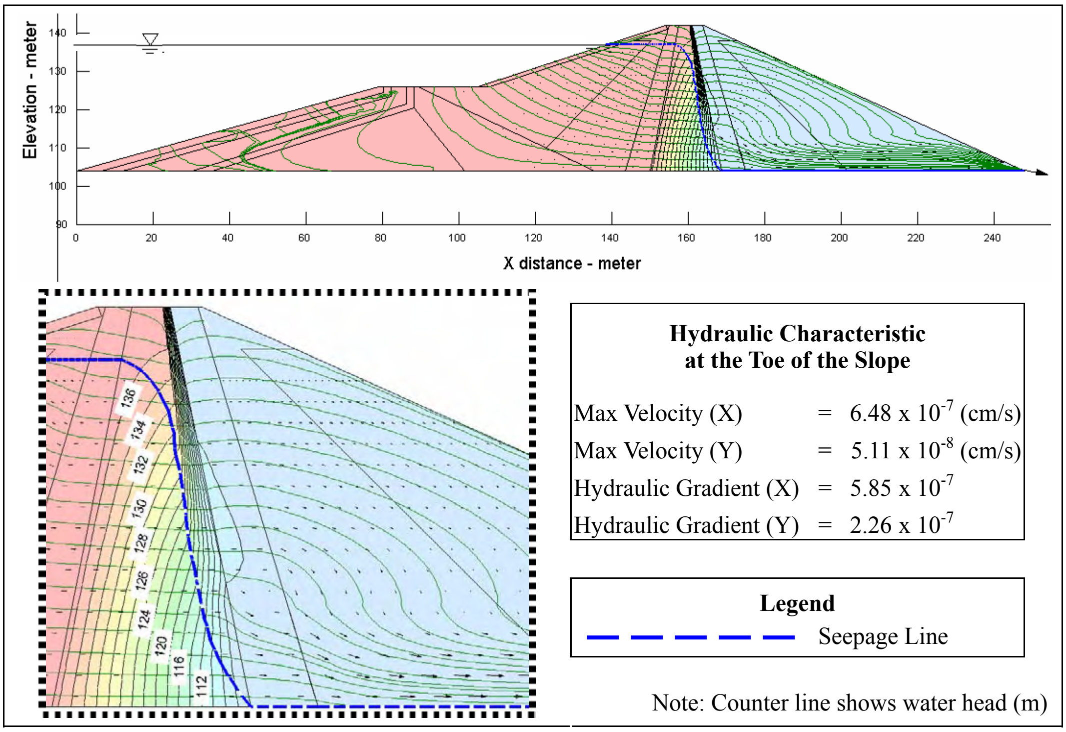



Source: JICA Study Team

**Figure 2.3.2 Flow Line at NHWL of El. 136.0 m**

### (2) Case 2: NHWL of EL. 137.0 m

The seepage line and flow line at NHWL of EL. 137.0 m is shown in the figure below:

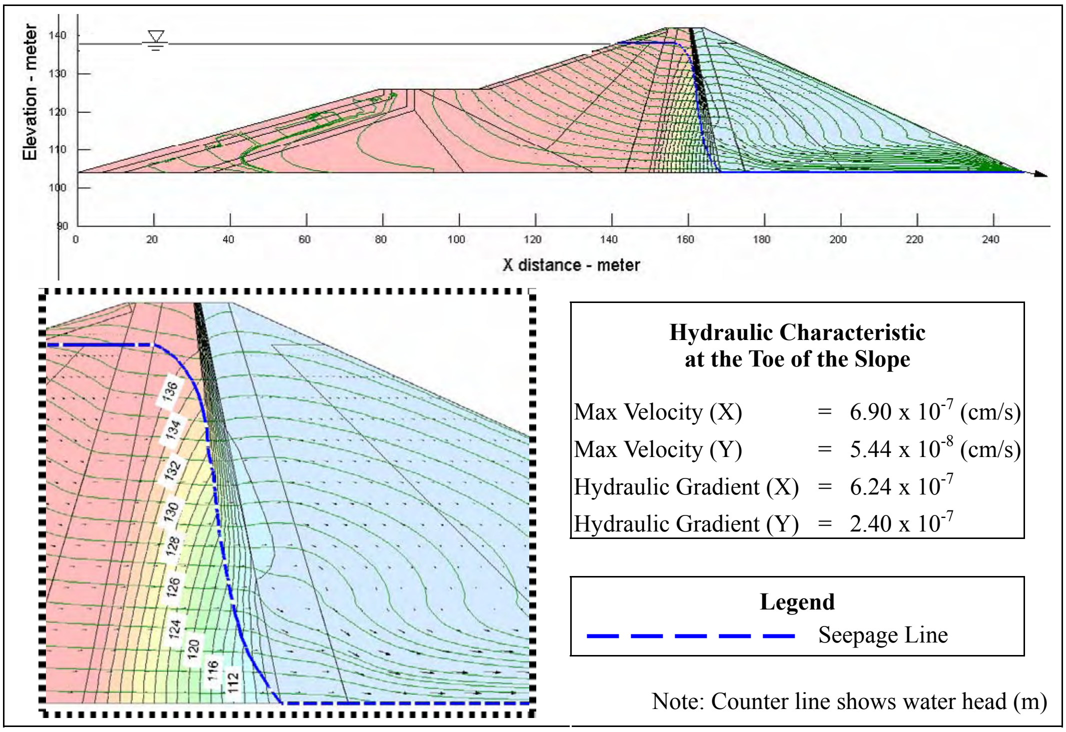



Source: JICA Study Team

**Figure 2.3.3 Flow Line at NHWL of El. 137.0 m**

(3) Case 3: NHWL of EL. 138.0 m

The seepage line and flow line at NHWL of EL. 138.0 m is shown in the figure below:

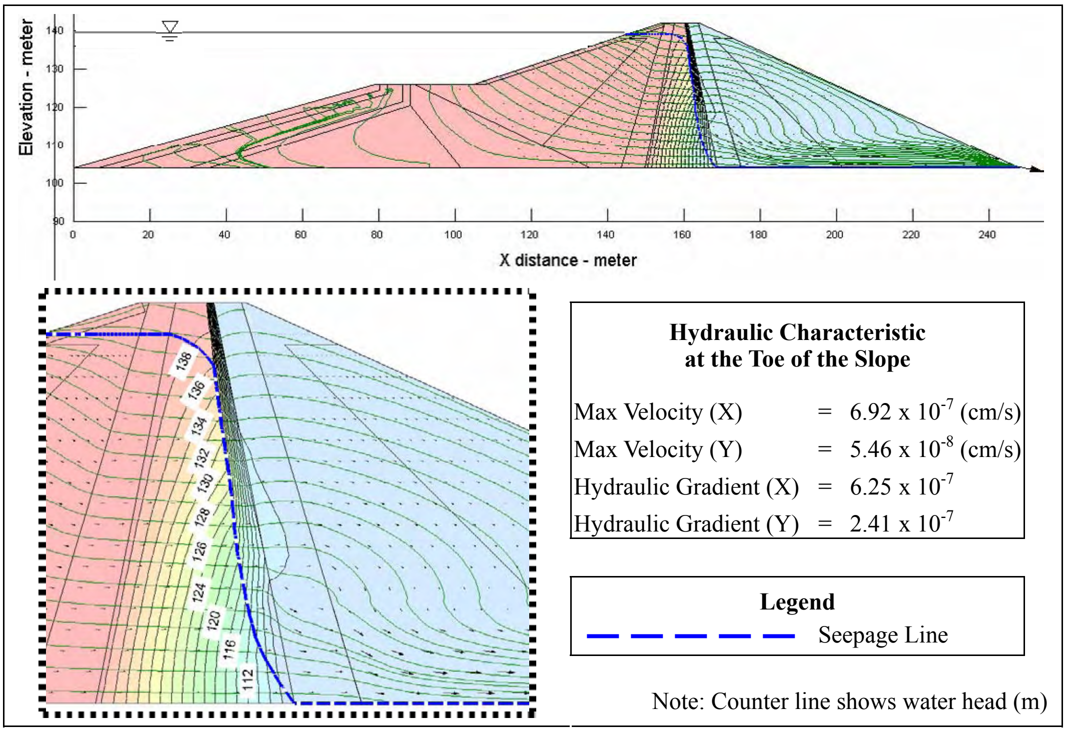



Source: JICA Study Team

**Figure 2.3.4 Flow Line at NHWL of El. 138.0 m**

(4) Case 4: NHWL of EL. 139.0 m

The seepage line and flow line at NHWL of EL. 139.0 m is shown in the figure below:




Source: JICA Study Team

**Figure 2.3.5 Flow Line at NHWL of El. 139.0 m**

## 2.4 Conclusion

(1) Comparison with the Past Analysis Result

Compared with the flow net obtained in the past analysis shown in Design Calculations 1978 (Figure 2.2.1), there is a little difference between them. The flow net obtained by SEEP/W shows that seepage lines seem to fall to the ground level of El 104.0 m within the center core in all cases.

(2) Safety against Seepage Failure

With respect to piping occurring in dam body, soil particles would be easily eroded at the toe of slope because seepage flow velocity and hydraulic gradient are largest there. In order to check such a seepage failure, the safety at the toe of the core part was studied for reference. The dam safety where the surface of pervious foundation in downstream side is covered by cohesive soil is checked by the following equation:

$G/W = (\rho \times H) / (\rho_w \times P) > 1.0$

where,
- $G$ = weight of covering layer ($tf/m^3$)
- $W$ = uplift pressure acting to the bottom of the covering layer ($tf/m^3$)
- $\rho$ = density of covering layer ($t/m^3$)
- $H$ = height of covering layer (m)
- $\rho_w$ = density of water ($t/m^3$)
- $P$ = pressure head at the bottom of covering layer (m)

The following values are applied to the above equation:

- $\rho$ = 1.95 ($t/m^3$) as saturated density of the core
- $H$ = 20.6 (m) as the bottom width
- $\rho_w$ = 1.0 ($t/m^3$)
- $P$ = 35.0 (m) as the water depth for NHWL of EL. 139.0 m ($P = P_w/\rho g = \rho g h/\rho g = h$)

$G/W = (1.95 \times 20.6) / (1.0 \times 35.0) = 1.15 > 1.0$

Therefore the dam safety against seepage failure was confirmed for all the four cases.

(3) Preparation of Flow Nets for Stability Analysis

In the above calculation, four cases of flow net were prepared. However, it was concluded that the past flow net would be used for stability analysis in the next chapter because of three reasons as follows:

- The re-calculation was probatively carried out in order to compare with the past stability analysis result.
- The difference between the past and new flow nets seems to cause little influence to results of stability analysis.
- Comparison between the past analysis result and re-calculation using new method will be studied in stability analysis as well.

Stability analysis by using these flow nets will be discussed in the next chapter.

# CHAPTER 3 STABILITY ANALYSIS OF MAIN DAM

## 3.1 Purpose

As discussed in the Chapter 1 in this Supporting Report, it was concluded that NHWL can not be raised due to the constraint regulated by the flood control operation rule.

This chapter, however, will provide a consideration with an analysis result obtained by slip circle method using COSTANA, which is application software for stability analysis by composite slip surfaces method.

The purpose of this analysis is as follows:

1) To review the past analysis[2] carried out manually, and to ensure the present dam safety against slip failure by re-calculation using COSTANA.
2) To evaluate the dam safety factors for a few cases of raised NHWL.

## 3.2 Review of the Past Stability Analysis

According to the report on Wonogiri Multipurpose Dam Project Technical Guide Note issued in November 1981 (hereinafter called "Guide Note 1981"), the past stability analysis for the cofferdam and the main dam has been carried out after design modification of cofferdam in 1978. Since the most severe cases were identified in the original design in the case of reservoir full, the stability of the dam was checked in the same case. Conditions used for stability check were as follows:

Main dam : Reservoir full at WL of El. 136.0 m
Seismic coefficient, k=0.12
Acceptable value > 1.20

**Table 3.2.1 Design Values of Main Dam and Coffer Dam Materials**

| Item | | Unit | Material | | | | |
|---|---|---|---|---|---|---|---|
| | | | Core* | Filter | Rock – I (Spillway) | Random | Rock – II (Quarry) |
| Specific gravity | $G_s$ | | 2.70 | 2.70 | 2.40 | 2.70 | 2.44 |
| Dry density | $\gamma_d$ | $t/m^3$ | 1.51 | 1.80 | 1.80 | 1.80 | 1.68 |
| Wet density | $\gamma_t$ | $t/m^3$ | 1.87 | 2.00 | 1.90 | 2.00 | 1.85 |
| Saturated density | $\gamma_s$ | $t/m^3$ | 1.95 | 2.10 | 2.00 | 2.10 | 1.99 |
| Cohesion | c | $t/m^2$ | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Internal friction angle | Φ | Deg. | 13 | 35 | 37 | 35 | 37 |
| Permeability coefficient | k | cm/sec | $1.0 \times 10^{-6}$ | $2.6 \times 10^{-3}$ | – | $2.6 \times 10^{-3}$ | – |

Note *: Blending ratio of core material is Clay : Sand : Gravel = 3 : 5 : 2
Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

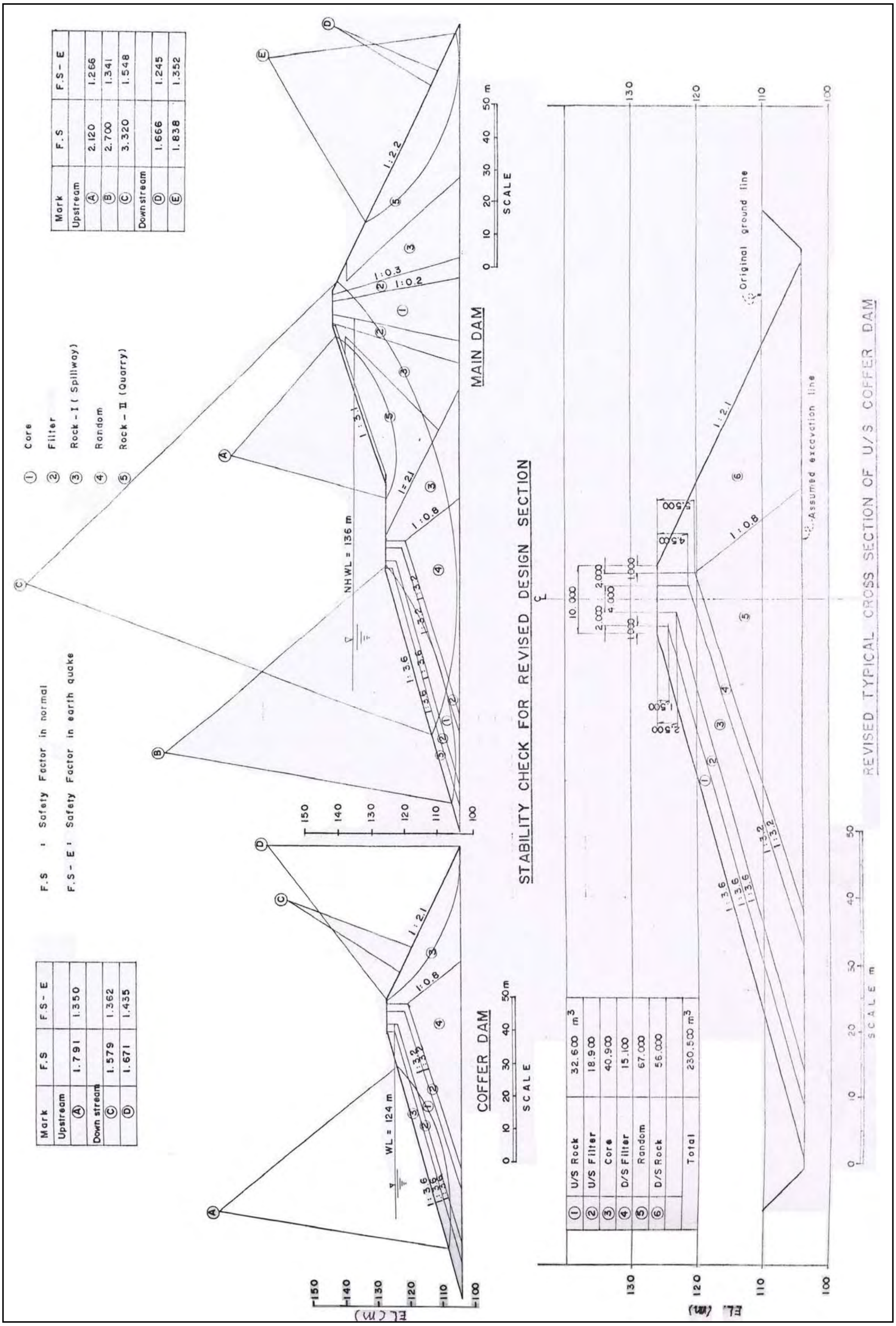
Result of stability check was shown in Figure 3.2.1 in the next page. As shown in the table below, all the cases satisfied that the safety factors were larger than 1.20.

**Table 3.2.2 The Minimum Safety Factors**

| Item | Upstream of the Main Dam | Downstream of the Main Dam |
|---|---|---|
| F.S. : Safety factor | 2.120 | 1.666 |
| F.S.-E : Safety factor for earthquake | 1.266 | 1.245 |

Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

[2] Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981, Nippon Koei Co., Ltd.




Source: Wonogiri Multipurpose Dam Project Technical Guide Note issued in November 1981

**Figure 3.2.1 Result of Stability Check in Guide Note 1981**

## 3.3 Stability Analysis by COSTANA

COSTANA is one of applications for stability analysis, which can be utilized for stability calculation of embank and cutting slope by circle slip or complex slip circle method.

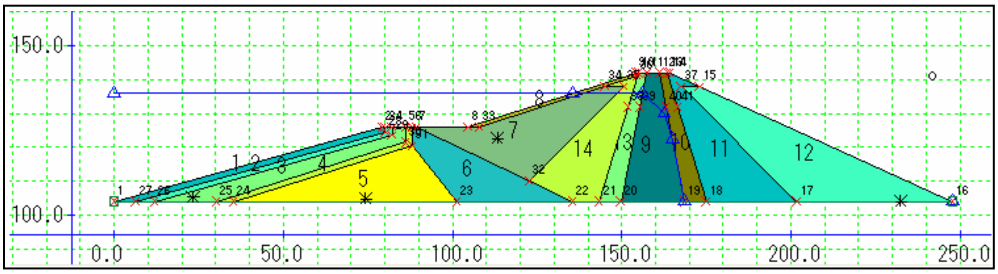
### 3.3.1 Condition for Calculation

(1) Design of Materials

According to Guide Note 1981, the design values of main dam and coffer dam materials are given as Table 3.2.1.

(2) Geological Layer Node Points

The body of main dam and coffer dam consist of 14 layers with the following 41 node points depending on the material types as shown in Figure 3.3.1. The node points to define the geological layer were given based on the drawing in Guide Note 1981 as shown in Table 3.3.1.




Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

**Figure 3.3.1 Geological Layer**

**Table 3.3.1 Geological Layer Node Points**

| Node No. | Coordinate | | Node No. | Coordinate | | Node No. | Coordinate | |
|---|---|---|---|---|---|---|---|---|
| | X (m) | Y (El.m) | | X (m) | Y (El.m) | | X (m) | Y (El.m) |
| 1 | 0.00 | 104.00 | 15 | 173.00 | 138.00 | 29 | 82.20 | 123.50 |
| 2 | 79.20 | 126.00 | 16 | 247.80 | 104.00 | 30 | 86.20 | 121.50 |
| 3 | 80.20 | 126.00 | 17 | 201.70 | 104.00 | 31 | 88.20 | 120.50 |
| 4 | 82.20 | 126.00 | 18 | 174.95 | 104.00 | 32 | 122.73 | 110.03 |
| 5 | 86.20 | 126.00 | 19 | 168.60 | 104.00 | 33 | 107.86 | 126.00 |
| 6 | 88.20 | 126.00 | 20 | 149.80 | 104.00 | 34 | 145.06 | 138.00 |
| 7 | 89.20 | 126.00 | 21 | 143.45 | 104.00 | 35 | 150.70 | 138.00 |
| 8 | 104.60 | 126.00 | 22 | 135.40 | 104.00 | 36 | 154.51 | 141.05 |
| 9 | 154.20 | 142.00 | 23 | 101.40 | 104.00 | 37 | 167.70 | 138.00 |
| 10 | 154.85 | 142.00 | 24 | 35.40 | 104.00 | 38 | 151.85 | 132.00 |
| 11 | 157.40 | 142.00 | 25 | 30.20 | 104.00 | 39 | 155.40 | 132.00 |
| 12 | 161.00 | 142.00 | 26 | 12.00 | 104.00 | 40 | 163.00 | 132.00 |
| 13 | 163.55 | 142.00 | 27 | 6.40 | 104.00 | 41 | 166.55 | 132.00 |
| 14 | 164.20 | 142.00 | 28 | 80.20 | 124.50 | - | - | - |

Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

The material properties of the respective layers are classified as shown in Table 3.3.2.

**Table 3.3.2 Characteristics of Materials**

| No. of Layer | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Material Property | 3 | 2 | 1 | 2 | 4 | 3 | 5 | 5 | 1 | 2 | 3 | 5 | 2 | 3 |

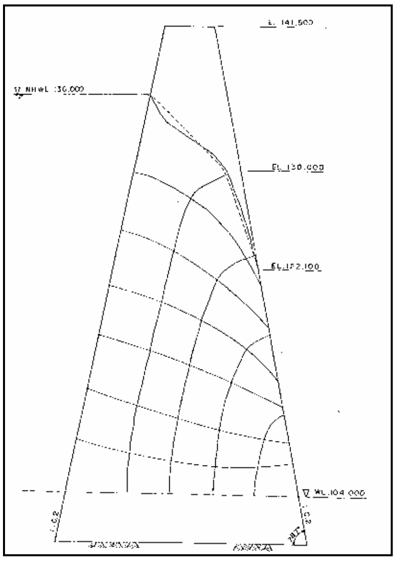
Note: Material property: 1) Core, 2) Filter, 3) Rock – I (Spillway), 4) Random, and 5) Rock – II (Quarry)
Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

(3) Water Level and Flow Net

Water unit weight of 1.020 tf/m$^3$ was applied.

Water level in the center core was set based on the flow net shown in Guide Note 1981, which was drawn as a flow at NHWL (Normal High Water Level) of El.136.0 m.

In this review analysis, the four (4) cases of NHWL were probatively provided; El.136.0 m, El.137.0 m, El.138.0 m and El.139.0 m in order to prove the respective safeties. In all the four cases, however, the same flow net at NHWL of EL. 136.0 m was applied.



Source: Wonogiri Multipurpose Dam Project Technical Guide Note

**Figure 3.3.2 Flow Net at NHWL**

(4) Never Line

Two points of never line was set at node points No.1 and No.16 so that circles don't exceed the ground level in the repeated calculation.

(5) Seismic Load

The same values of seismic coefficient were provided for all layers as 0.120 for horizontal direction and 0.000 for vertical direction.

(6) Slip Circle

In this analysis, the same five (5) circles as the most severe cases identified in the calculation of Feasibility Study, shown in Figure 3.2.1, were set based on the above-mentioned report. The coordinates of the center of the circles and slip directions are shown in Table 3.3.3.

**Table 3.3.3 Coordinates to Define Slip Circles**

| Circle | Slip Direction | Central Point of the Circle | | One Point through the Circle | |
|---|---|---|---|---|---|
| | | X (m) | Y (m) | X (m) | Y (m) |
| A | Left side | 113.24 | 171.38 | 113.24 | 122.60 |
| B | Left side | 23.20 | 191.19 | 23.20 | 105.22 |
| C | Left side | 74.26 | 232.05 | 74.26 | 104.79 |
| D | Right side | 241.96 | 140.89 | 232.36 | 104.00 |
| E | Right side | 232.36 | 161.32 | 232.36 | 140.00 |

Source: Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981

### 3.3.2 Equation for Safe Factor

The equation used for safety factor calculation is as follows:

$$SF = \frac{\sum\{cl + (N - U - N_e)\tan\varphi\}}{\sum(T + T_e)} \quad \text{.......... (i)}$$

SF: Safety factor

N : Vertical component of load on slip surface of each slice (dead weight: W + hydrostatic pressure: E)

T : Tangent component of load on slip surface of each slice (dead weight: W + hydrostatic pressure: E)

U : Pore pressure on slip surface of each slice

$N_e$: Vertical component of seismic inertia force on slip surface of each slice

$T_e$: Tangent component of seismic inertia force on slip surface of each slice

Φ : Internal frictional angle on slip surface of each slice
c : Cohesion on slip surface of each slice
l : Length of slip surface of each slice

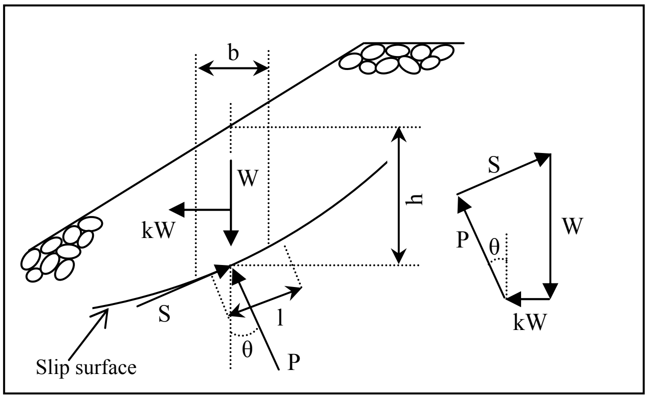
where, symbols used in the below-mentioned equation are expressed as below:

$\gamma_w$ : Water unit weight
$\gamma_t$ : Wet density
$\gamma_s$ : Saturated density
k : Seismic coefficient
u : Pre pressure per unit length

(1) Empty reservoir (see Figure 3.3.3)

This case means a case of empty reservoir or a case that water level in the reservoir is below a slip circle.

$N = W\cos\theta = bh\gamma_t\cos\theta$
$N_e = kW\sin\theta = kbh\gamma_t\sin\theta$
$U = u \bullet l = u \bullet b/\cos\theta$
$T = W\sin\theta = bh\gamma_t\sin\theta$
$T_e = kW\cos\theta = kbh\gamma_t\cos\theta$




Source: JICA Study Team

**Figure 3.3.3 Load by Slice Method (Empty Reservoir)**

(2) Full supply level (see Figure 3.3.4)

This case means a case of full supply level or a case that water level in the reservoir is above a slip circle.

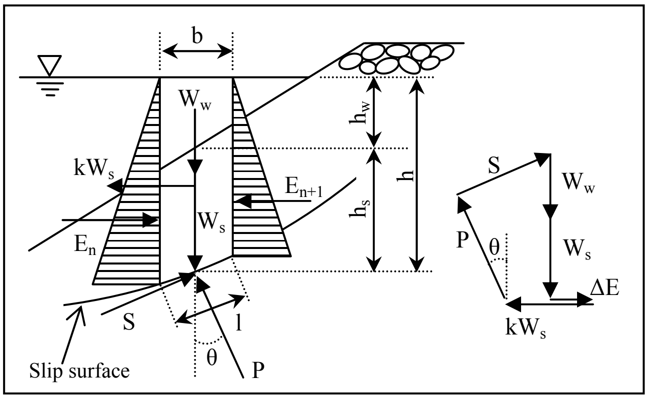
$$
\begin{aligned}
N &= W\cos\theta + \Delta E\sin\theta \\
&= (W_s + W_w)\cos\theta + (E_n - E_{n+1})\sin\theta \\
&= (\gamma_s h_s + \gamma_w h_w)\, b\cos\theta + \{\tfrac{1}{2}\gamma_w (h + \tfrac{1}{2} b\tan\theta)^2 - \tfrac{1}{2}\gamma_w (h - \tfrac{1}{2} b\tan\theta)^2\}\sin\theta \\
&= (\gamma_s h_s + \gamma_w h_w)\, b\cos\theta + \gamma_w h\, b\sin^2\theta / \cos\theta \\
&= (\gamma_s h_s + \gamma_w (h - h_s))\, b\cos\theta + \gamma_w h\, b\sin^2\theta / \cos\theta \\
&= (\gamma_s - \gamma_w)\, h_s b\cos\theta + \gamma_w h\, b / \cos\theta
\end{aligned}
$$

$N_e = W_s k\sin\theta = k\gamma_s h_s b\sin\theta$

$U = u \bullet l = \gamma_w h\, b / \cos\theta$

$$
\begin{aligned}
T &= W\sin\theta - \Delta E\cos\theta \\
&= (W_s + W_w)\sin\theta - (E_n - E_{n+1})\cos\theta \\
&= (\gamma_s h_s + \gamma_w h_w)\, b\sin\theta - \{\tfrac{1}{2}\gamma_w (h + \tfrac{1}{2} b\tan\theta)^2 - \tfrac{1}{2}\gamma_w (h - \tfrac{1}{2} b\tan\theta)^2\}\cos\theta \\
&= (\gamma_s h_s + \gamma_w h_w)\, b\sin\theta - \gamma_w h\, b\sin\theta \\
&= (\gamma_s - \gamma_w)\, h_s b\sin\theta
\end{aligned}
$$

$T_e = W_s\ k\ \cos\theta = k\ \gamma_s h_s b\ \cos\theta$




Source: JICA Study Team

**Figure 3.3.4 Load by Slice Method (Full Supply Level)**

(3) Partial supply level (see Figure 3.3.5)

This case means a case of partial supply level or a case that water level in the reservoir crosses with a slip circle.

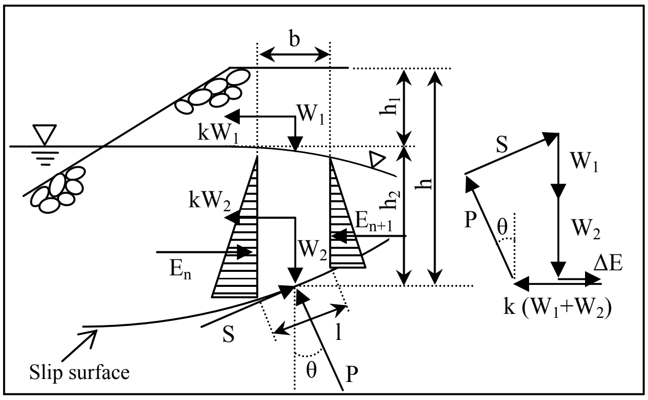
$$
\begin{aligned}
N &= W\cos\theta + \Delta E\sin\theta \\
&= (W_1 + W_2)\cos\theta + (E_n - E_{n+1})\sin\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ b\cos\theta + \{\tfrac{1}{2}\gamma_{sat}(h + \tfrac{1}{2}b\tan\theta)^2 - \tfrac{1}{2}\gamma_{sat}(h - \tfrac{1}{2}b\tan\theta)^2\}\sin\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ b\cos\theta + \gamma_{sat}\ h\ b\sin^2\theta / \cos\theta \\
&= (\gamma_t(h - h_2) + \gamma_{sat} h_2)\ b\cos\theta + \gamma_{sat}\ h\ b\sin^2\theta / \cos\theta \\
&= (\gamma_{sat} - \gamma_t)\ h_2\ b\cos\theta + \gamma_t h\ b\cos\theta + \gamma_{sat}\ h\ b\sin^2\theta / \cos\theta
\end{aligned}
$$

$$
\begin{aligned}
N_e &= (W_1 + W_2)\ k\sin\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ k\ b\sin\theta \\
&= \{\gamma_t(h - h_2) + \gamma_{sat} h_2\}\ k\ b\sin\theta \\
&= (\gamma_{sat} - \gamma_t)\ h_2\ k\ b\sin\theta + \gamma_t h\ k\ b\sin\theta
\end{aligned}
$$

$$
\begin{aligned}
U &= u \bullet l = u \bullet b / \cos\theta \\
&= \gamma_w\ h_2\ b / \cos\theta
\end{aligned}
$$

$$
\begin{aligned}
T &= W\sin\theta - \Delta E\cos\theta \\
&= (W_1 + W_2)\sin\theta - (E_n - E_{n+1})\cos\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ b\sin\theta - \{\tfrac{1}{2}\gamma_{sat}(h + \tfrac{1}{2}b\tan\theta)^2 - \tfrac{1}{2}\gamma_{sat}(h - \tfrac{1}{2}b\tan\theta)^2\}\cos\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ b\sin\theta - \gamma_{sat}\ h\ b\sin\theta \\
&= \{\gamma_t(h - h_2) + \gamma_{sat} h_2\}\ b\sin\theta - \gamma_{sat}\ h\ b\sin\theta \\
&= (\gamma_{sat} - \gamma_t)\ h_2\ b\sin\theta + \gamma_t\ h\ b\sin\theta - \gamma_{sat}\ h\ b\sin\theta
\end{aligned}
$$

$$
\begin{aligned}
T_e &= (W_1 + W_2)\ k\cos\theta \\
&= (\gamma_t h_1 + \gamma_{sat} h_2)\ k\ b\cos\theta \\
&= (\gamma_{sat} - \gamma_t)\ h_2\ k\ b\cos\theta + \gamma_t h\ k\ b\sin\theta
\end{aligned}
$$




Source: JICA Study Team

**Figure 3.3.5 Load by Slice Method (Partial Supply Level)**

### 3.3.3 Result of Re-calculation for the Cases in Guide Note 1981[3]

#### (1) Purpose of Re-calculation

In order to verify the calculation method by COSTANA and to review the validity of safety factors calculated in Guide Note 1981, recalculation was made with the same slip circle under the same condition as the past analysis.

#### (2) Method

The coordinates of (i) the central points of the slip circles and (ii) one point through the circle were estimated based on the drawing in the report (Guide Note 1981). Calculation was conducted fixing those two points with the fixed NHWL of El.136.0 m, the same level as the calculation in Guide Note 1981.

#### (3) Result

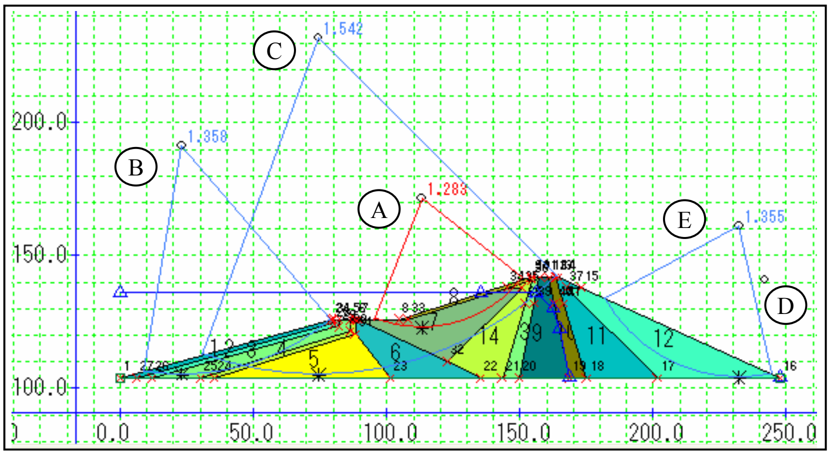
The respective safety factors (= S.F.) and safety factors for earthquake (= S.F.-E) were calculated as shown in Table 3.3.4. The safety factors obtained from the calculation using COSTANA were almost same as the results in Guide Note 1981. The difference between them was confirmed with an accuracy of 2.98% for S.F. and 0.22% for S.F.-E on average. The circle “D” is not calculated in this analysis since it causes only slight slip.

**Table 3.3.4 Result of Re-calculation of Year 1981**

| Circle | Central coordinates | | Radius (m) | Minimum Safety Factor | | | |
|---|---|---|---|---|---|---|---|
| | X (m) | Y (m) | | Guide Note 1981 | | COSTANA | |
| | | | | S.F. | S.F.-E | S.F. | S.F.-E |
| A | 113.24 | 171.38 | 48.78 | 2.120 | 1.266 | 2.347 | 1.283 |
| B | 23.20 | 191.19 | 85.97 | 2.700 | 1.341 | 2.724 | 1.358 |
| C | 74.26 | 232.05 | 127.26 | 3.320 | 1.548 | 3.359 | 1.542 |
| D | 241.96 | 140.89 | 33.46 | 1.666 | 1.245 | - | - |
| E | 232.36 | 161.32 | 57.32 | 1.838 | 1.352 | 1.842 | 1.355 |

Notes: S.F. = Safety Factor, S.F.-E = Safety Factor against Earthquake
Source: JICA Study Team

[3] Report on Wonogiri Multipurpose Dam Project Technical Guide Note, November 1981



Source: JICA Study Team

**Figure 3.3.6 Slip Circle of Re-calculation of Year 1981**

### 3.3.4 Result of Calculation for Cases of Raising NHWL

#### (1) Case I: The Center of the Circle Is Fixed

The same circles as Guide Note 1981 are used and the result is shown in Table 3.3.5.

**Table 3.3.5 Result of Calculation with Fixed Circle**

| Circle | | EL.136.0 m | | EL.137.0 m | | EL.138.0 m | | EL.139.0 m | |
|---|---|---|---|---|---|---|---|---|---|
| | | Radius (m) | S.F. | Radius (m) | S.F. | Radius (m) | S.F. | Radius (m) | S.F. |
| A | S.F. | 48.78 | 2.347 | 48.78 | 2.425 | 48.78 | 2.505 | 48.78 | 2.578 |
| | S.F.-E | 48.78 | 1.283 | 48.78 | 1.290 | 48.78 | 1.300 | 48.78 | 1.310 |
| B | S.F. | 85.97 | 2.724 | 85.97 | 2.724 | 85.97 | 2.724 | 85.97 | 2.724 |
| | S.F.-E | 85.97 | 1.358 | 85.97 | 1.358 | 85.97 | 1.358 | 85.97 | 1.358 |
| C | S.F. | 127.26 | 3.359 | 127.26 | 3.427 | 127.26 | 3.497 | 127.26 | 3.569 |
| | S.F.-E | 127.26 | 1.542 | 127.26 | 1.549 | 127.26 | 1.558 | 127.26 | 1.568 |
| D | S.F. | - | - | - | - | - | - | - | - |
| | S.F.-E | - | - | - | - | - | - | - | - |
| E | S.F. | 57.32 | 1.842 | 57.32 | 1.842 | 57.32 | 1.842 | 57.32 | 1.842 |
| | S.F.-E | 57.32 | 1.355 | 57.32 | 1.355 | 57.32 | 1.355 | 57.32 | 1.355 |

Source: JICA Study Team

#### (2) Case II: The Center of the Circle Is Unfixed

A center of circle is automatically searched by repeated calculation so that a safe factor becomes the smallest in the range of 10 m from the Guide Note 1981's calculation. The result is shown in Table 3.3.6.

**Table 3.3.6 Result of Calculation with Unfixed Circle**

| Circle | | EL.136.0 m | | EL.137.0 m | | EL.138.0 m | | EL.139.0 m | |
|---|---|---|---|---|---|---|---|---|---|
| | | Radius (m) | S.F. | Radius (m) | S.F. | Radius (m) | S.F. | Radius (m) | S.F. |
| A | S.F. | 50.26 | 2.232 | 50.26 | 2.295 | 50.26 | 2.365 | 50.26 | 2.442 |
| | S.F.-E | 47.40 | 1.266 | 49.31 | 1.271 | 50.26 | 1.277 | 50.26 | 1.287 |
| B | S.F. | 83.14 | 2.755 | 83.14 | 2.755 | 83.14 | 2.755 | 83.14 | 2.755 |
| | S.F.-E | 83.14 | 1.350 | 83.14 | 1.350 | 83.14 | 1.350 | 83.14 | 1.350 |
| C | S.F. | 131.07 | 3.317 | 131.09 | 3.391 | 131.12 | 3.468 | 131.16 | 3.545 |
| | S.F.-E | 131.09 | 1.536 | 131.12 | 1.545 | 131.16 | 1.554 | 131.21 | 1.564 |
| D | S.F. | - | - | - | - | - | - | - | - |
| | S.F.-E | - | - | - | - | - | - | - | - |
| E | S.F. | 62.00 | 1.802 | 62.00 | 1.802 | 62.00 | 1.802 | 62.00 | 1.802 |
| | S.F.-E | 62.00 | 1.330 | 62.00 | 1.330 | 62.00 | 1.330 | 62.00 | 1.330 |

Source: JICA Study Team

(3) Result

In the above both cases (I) and (II), there are two kinds of tendency when NHWL is raised as follows:

(a) A safe factor is constant : circles B and E
(b) A safe factor increases : circles A and C

For all the above cases, the safety factors exceeded the acceptable value of 1.20.

## 3.4 Conclusion

(1) Comparison with the Past Analysis Result

As shown in Table 3.3.4, there is little difference between the past analysis result and the COSTANA's one. It was confirmed that COSTANA can be used for dam stability analysis in future.

(2) Safety against Slip Failure

As shown in Tables 3.3.5 and 3.3.6, the calculated minimum safety factors for all the cases exceed a value of 1.2 which is required as a minimum safety in the design criteria for fill type dam. Therefore, the obtained safety factors are satisfactory for the stability of the Wonogiri dam.

(3) Stability analysis for drawdown

Although stability analysis for drawdown of the reservoir water level in this Study, it is strongly recommended that such a study under the condition of residual water pressure is carried out if NHWL in the operation manual would be raised.