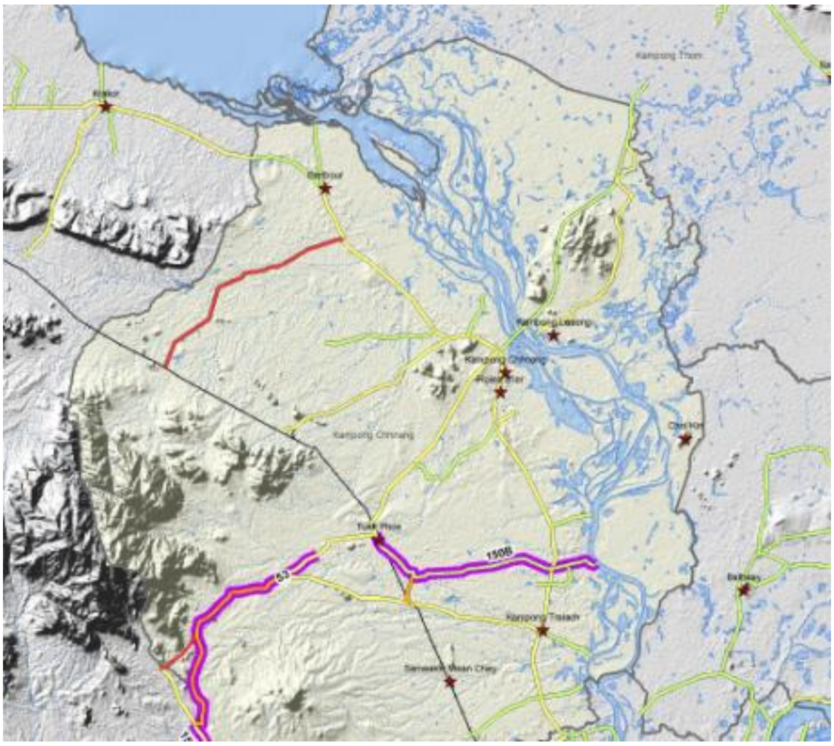
Climate Resilience for Provincial Road Improvement Project

Loan 2839-CAM (SF)/ 8254-CAM and Grant 0278-CAM



Flood Risk Management Interface Manual

September 2015

Contents

List of Appendices

List of figures

List of tables

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials BD
ADB	Asian Development Bank
Bank	The Asian Development Bank
CCAM	Conformal Cubic Atmospheric Model
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DGPS	Differential GPS
DoM	Department of Meteorology
EMP	Environmental Management Plan
EMS	Emergency Management System
FS	Feasibility Study
FRMI	Flood Risk Management Interface
GCM	Global Climate Model
GIS	Geographic Information System
GPS	Global Positioning System
IDF	Rainfall Intensity Duration and Frequency curves
IPPC	Intergovernmental Panel on Climate Change
IRI	International Roughness Index
JICA	Japan International Cooperation Agency
MEF	Ministry of Economics and Finance
MOE	Ministry of Environment
MOU	memorandum of understanding
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
MRC	Mekong River Commission
MRD	Ministry of Rural Development
NDMC	National Disaster Management Committee
OJT	On-The-Job Training
PMU	Project Management Unit
PPCR	Pilot Project for Climate Resilience
PDPWT	Provincial Department of Public Works and Transport
RAMS	Road Asset Management System of MPWT
SRTM	Shuttle Radar Topographic Mission
TOR	Terms of Reference
UAVS	Unmanned Aerial Vehicle System
USD	United States Dollar

1 Flood Proofing Roads

Improving the resilience of roads to climate effects, mainly in terms of flooding effects, is a complex process that involves many fields of science and related specialists. To simplify this process, the MPWT has commisioned a technical assistance study under the Provincial Road Improvement Project, which developed several tools and guidelines. It is shown below.

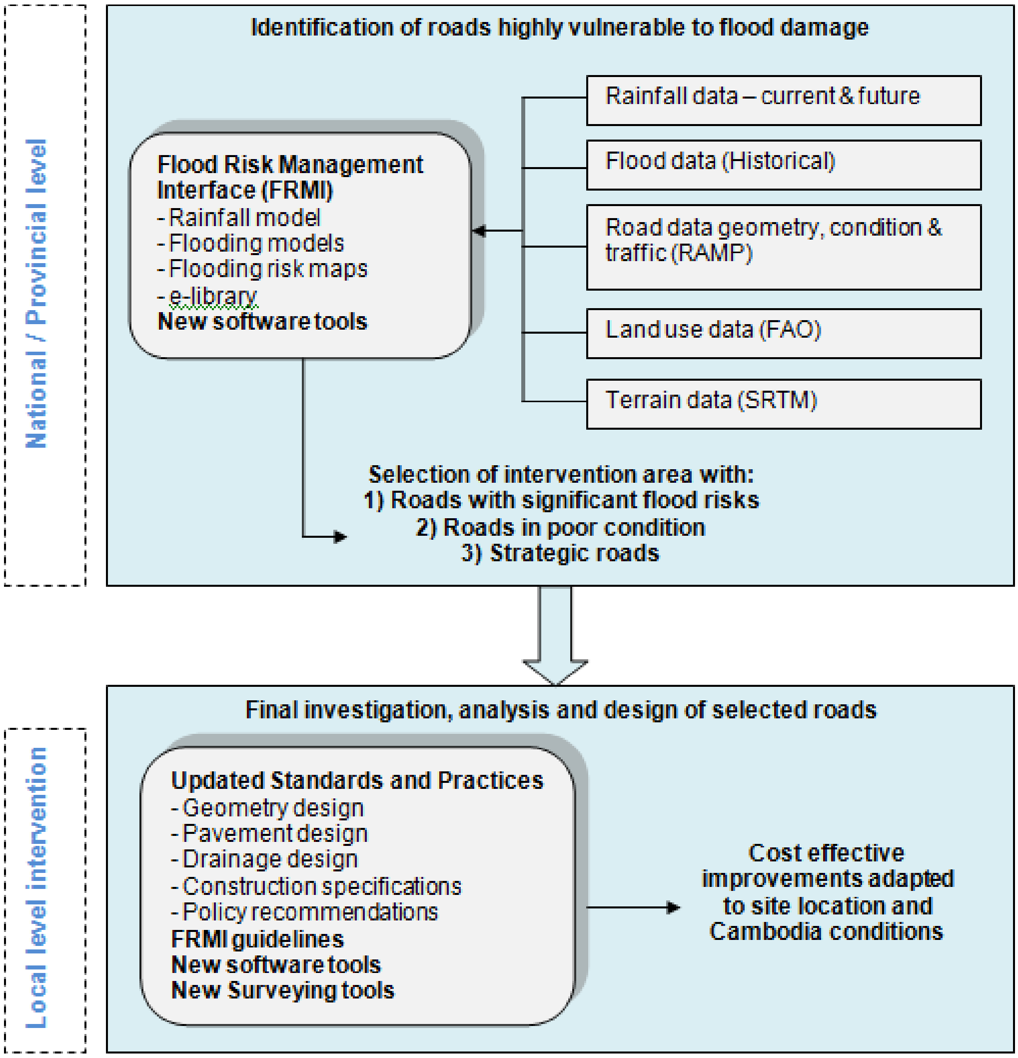


Figure 1 Overall road flood proofing process

The overal process of flood proofing mainly consists of a planning and prioritization phase that is carried out at national or provincial level and a design phase that is conducted locally once the preferred sites are identified.

Using several models, the risk of flood impacts and damage on roads is evaluated and allows the selection of vulnerable roads to be flood proofed. Depending on the risk level, recommendations are provided to facilitate the road strengthening and rehabilitation process.

One of the main tool developed for facilitating the flood proofing process and as a knowledge management platform was named Flood Risk Management Interface. That application was build with Microsoft Access, a powerful but relatively easy to use database software.

2 Aim of Flood Risk Management Interface for Roads

The main aim of the application is to provide easy access to existing information about the flood effects on the Cambodian road network, to evaluate the risk of flood damages and impacts on the network and to provide guidelines for improving the resilience of roads.

The Interface enables the user to directly access the relevant data for each individual road section and display, copy and use the required information for purposes such as:

- assessing the flood risk for individual roads in view of various types of flooding, based on current land use and rainfall patterns
- assessing the flooding risk for individual roads for current and future climatic condition (all other aspects being constant)
- prioritizing climate proofing interventions on the basis of flood risk assessment and deciding on the level of intervention
- accessing various road characteristics and condition data, including type, location and condition of existing bridges and culverts
- visualizing the results of post flooding damage assessments
- carrying out checks on roads designs, concerning road drainage or alignment proposals

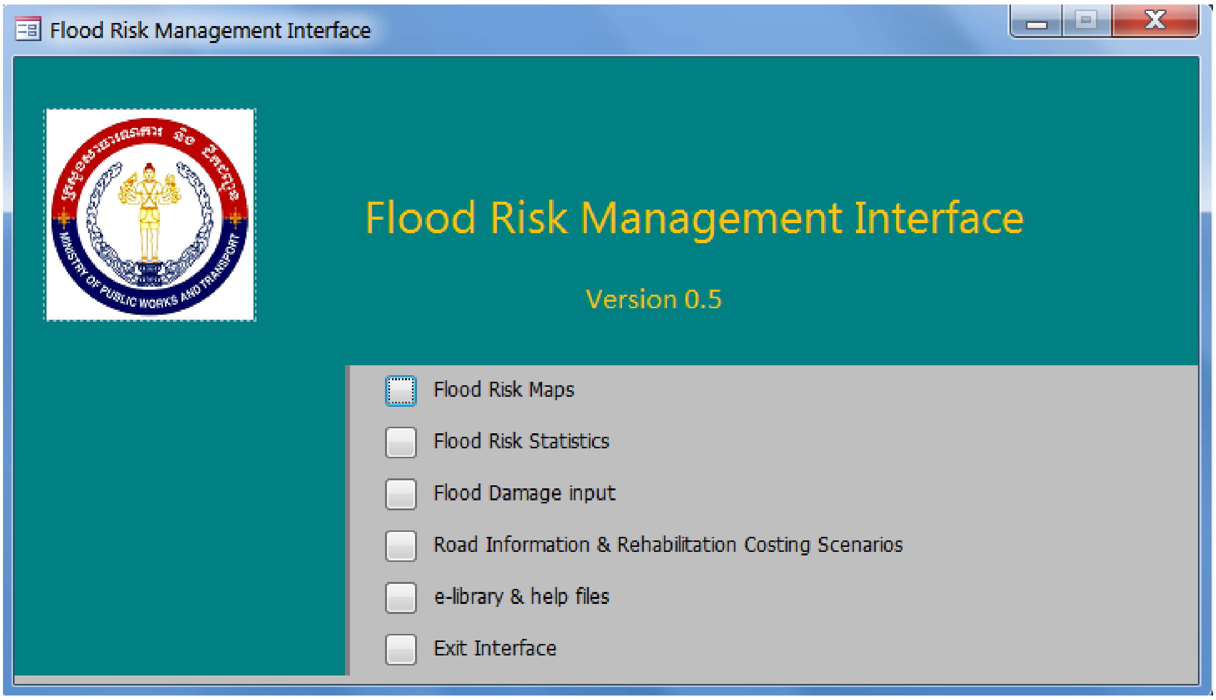


Figure 2 Flood risk management interface main menu

The application comprises five main menus:

1. Flood Risk Maps
2. Flood Risk Statistics
3. Flood Damage Input
4. Road Information and rehabilitation costing scenarios
5. E-library and Help Files

3 Flood Risk Maps and Statistics

One of the main outputs of the PRIP - CR output are flood risk damage maps for various types of floods. All maps are directly linked to the application and can be accessed by the user directly from the interface without the need to open any specific mapping program. The maps are organized on national and provincial level. However, it is also possible to display information on individual road sections as a map, a report, or both.

The main output of the road vulnerability maps is the development of four road risk flooding damage indexes corresponding to different flood types. Another index was build with the combination of the risk of the four flood type for prioritization purposes. These indexes were then associated to all national and provincial roads of the current Cambodian road network, using a model of about 550 individual road sections (about 11,500 km) linked to the MPWT Road Asset Management System (RAMS) data, which is at the core of the current road maintenance practice in the country.

The five flood risk indexes are:

- Flash Flood Index
- Large Drainage Area Index
- Build-up Area Flooding Index
- Low Land Flooding Index
- Combined flood risk index

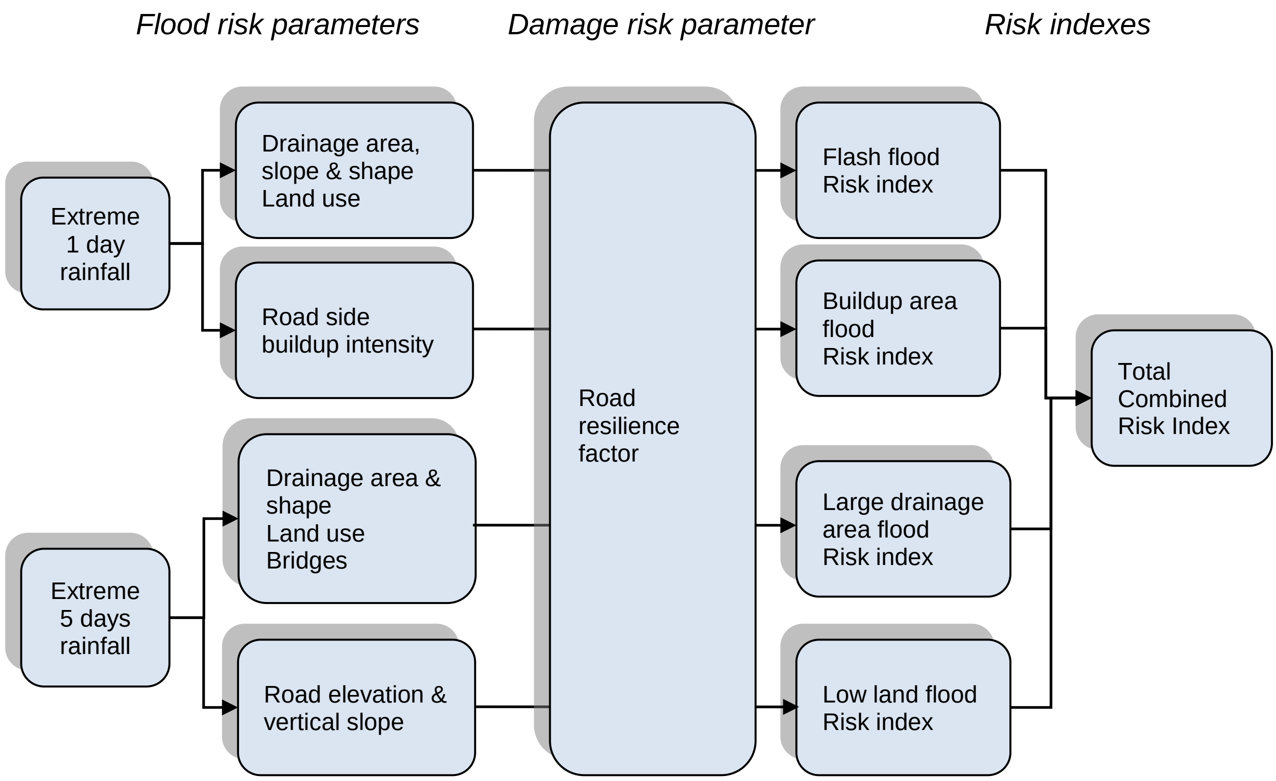


Figure 3 Flood risk calculation process

The calculation process starts by evaluating the risk of occurrence of the four types of flood and then takes the issue to the next level by introducing factors to account for the resilience of the road to these floods. It is important to understand that experiencing flooding or being subject to flood risk does not necessarily inflict a lot of damage to every road. Roads properly designed and maintained in perfect condition will remain at no or at very low risk of flood damage. For example, roads having being recently rehabilitated under major rehabilitation projects will have been upgraded to better withstand flood damages, as prescribed in the Cambodia road standards and in most international road design standards, and are likely to be considerably less damaged through flooding than un-rehabilitated roads. Road resilience is therefore assessed in the model through three indicators, the pavement surface roughness, the pavement type and the condition of the drainage structures. The overall equation is as follows:

Flood damage risk = Risk of flood occurrence x Road condition factors

All these indexes are the basic tools for prioritizing the climate proofing of individual road sections. The results of these flooding risk analyses can be documented in the form of tables, reports and flood risk maps.

A further major output of the project activity has been the investigation of the impact of climate change on the flood risk situation.

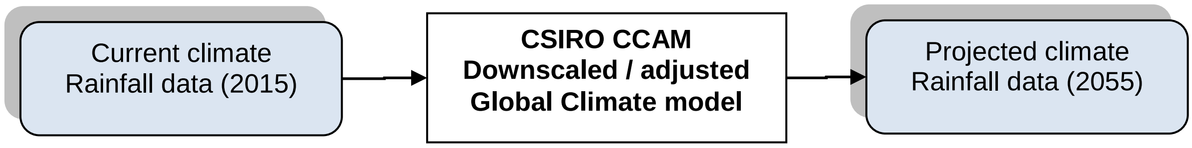


Figure 4 Climate change analysis

Thus, a climate change scenario calculation using the projected 2055 rainfall data has been carried out and the results of these changes where compared to the existing situation. The relevant maps have been produced as part of the CR-PRIP output, at the national scale and for all the provinces.

To map out the five flood indexes for the 25 provinces and to account for the climate change scenarios, more than 250 different maps were produced during the technical assistance. The Flood Risk Management Interface provides direct access to these maps either through the source application[1] (ARC GIS or Global Mapper) or through graphic formats (jpg or pdf).

The types of maps available are listed in the following table.

Table 1 Types of Maps

Map type
Road references (Link IDs)
Flood damage risks – current conditions
Flood damage risks – future conditions
Flood damage risk changes in time

The process of searching a map is facilitated by the following menu.

[1] Requires separate installation

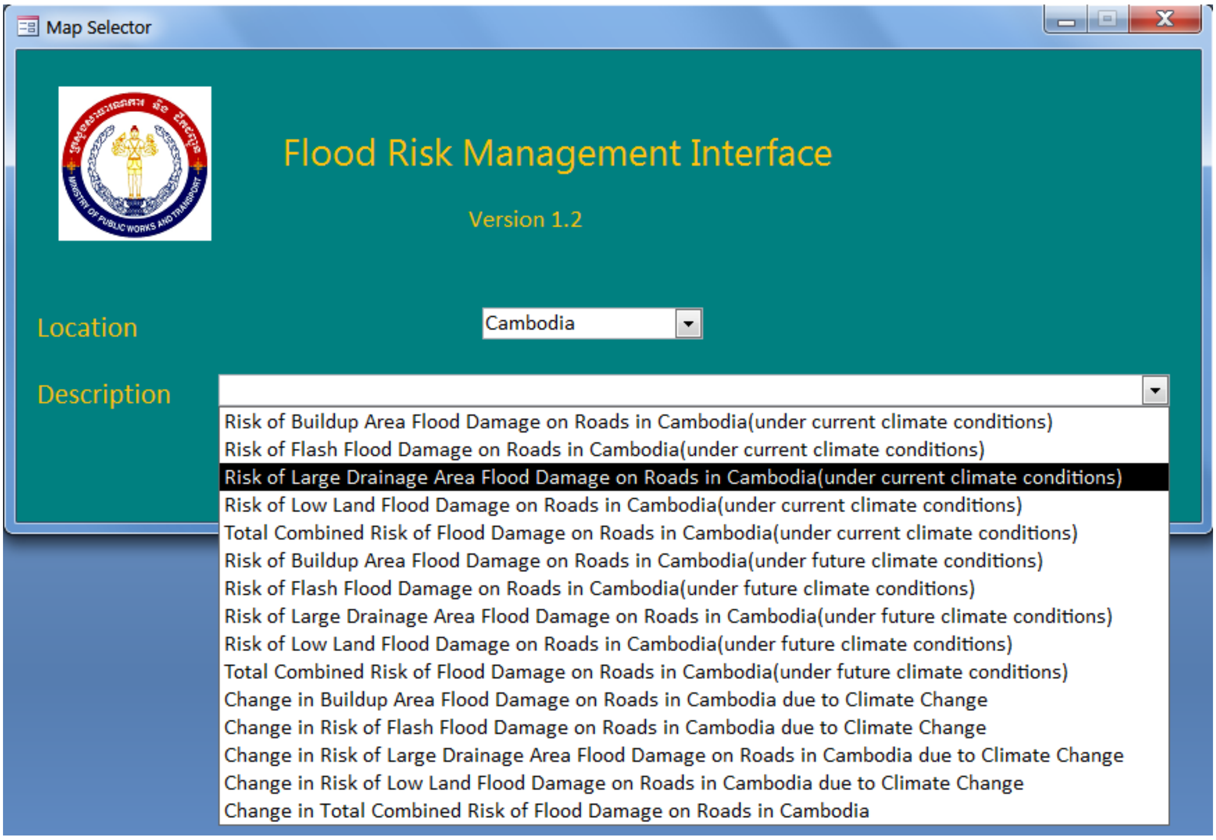


Figure 5 Flood map selection

A typical flood damage risk map shows the road sections associated with four risk levels, ranging from high (red), moderate (orange), low (yellow) to none (green).

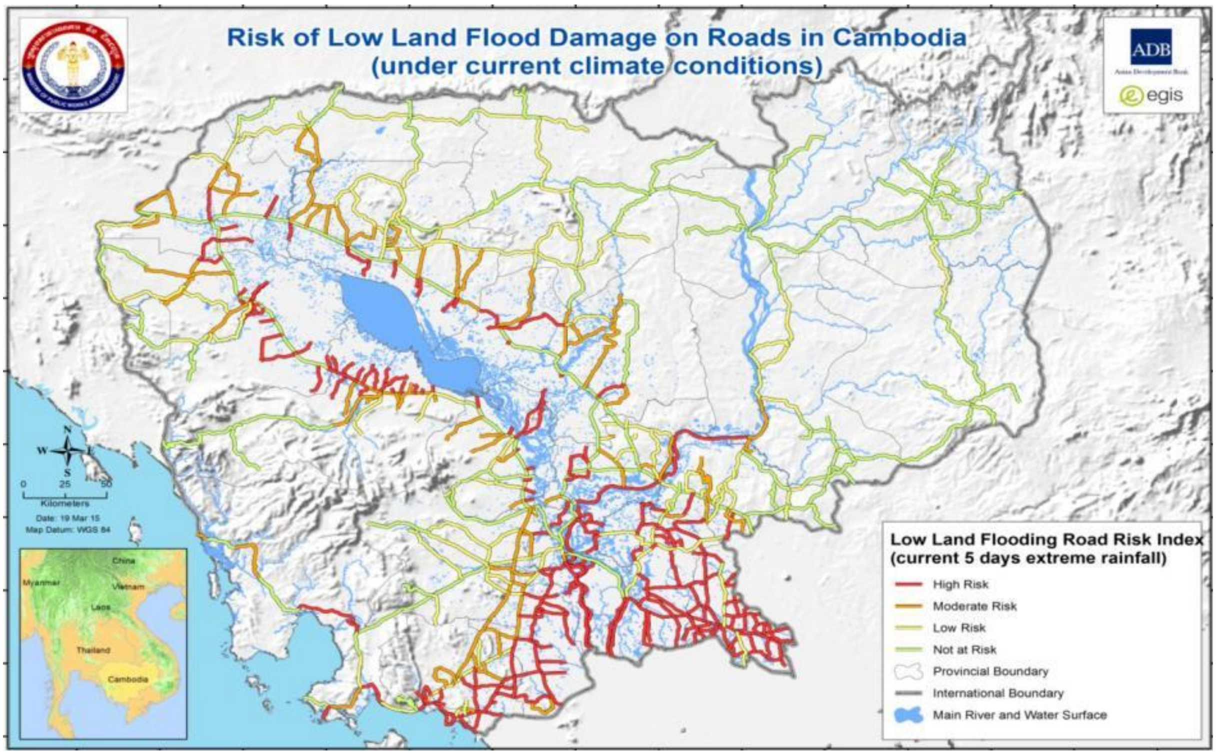


Figure 6 flood damage risk map

This menu enables the extraction of flood risk data and statistics per type of flood or per road for a particular province in view to create a report with that data.

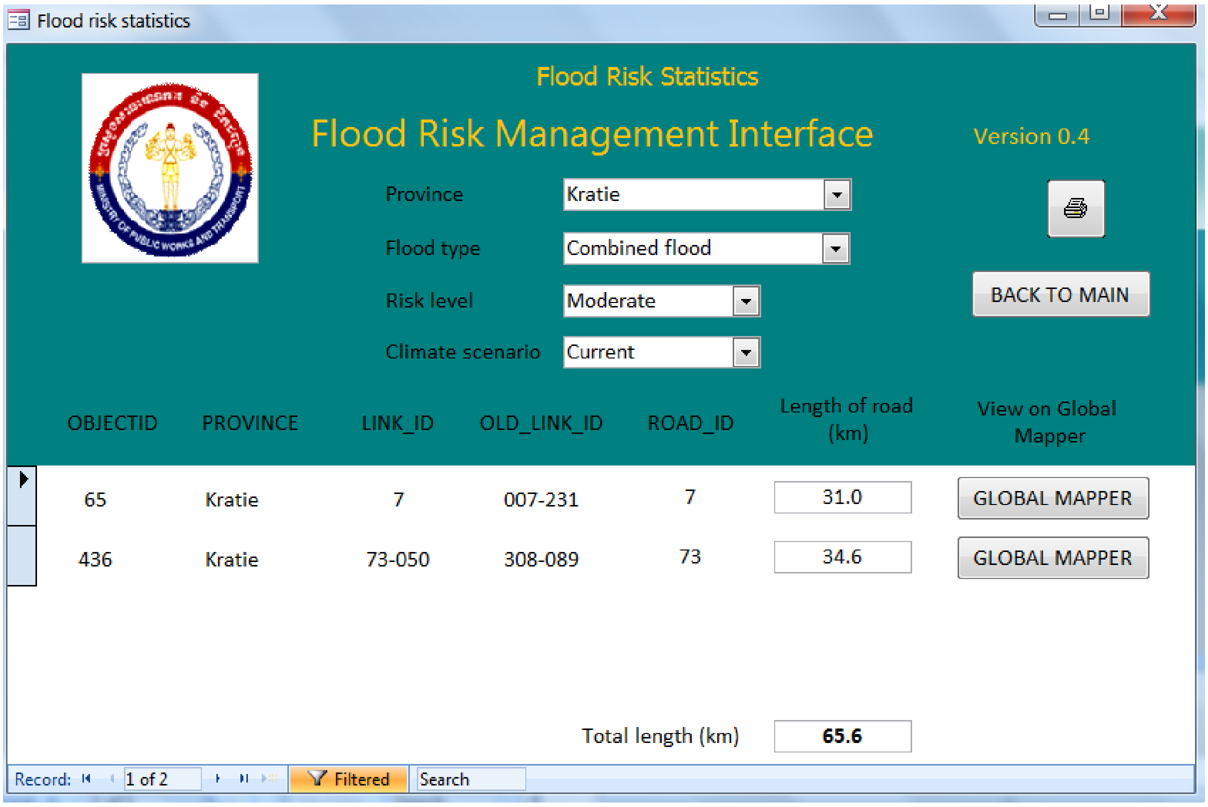


Figure 7 Retrieval of road risk data

More details on the modelling techniques are given in Appendix 1.

4 Flood Damage Database

Flood damage information for recent major floods of 2011 and 2013 has been gathered by the provincial offices at the MPWT and compiled into reports. However, this information was found to be difficult to interpret at a national scale since the basis for collecting that data has never been normalized. Therefore, in order to complement the current flood damage data collection activities at MPWT, the consultant has developed a new tool to visualize the extent and scope of future flood damage. With that tool a better understanding of the areas at risk will be obtained and possible adjustments to the flood risk models can be investigated.

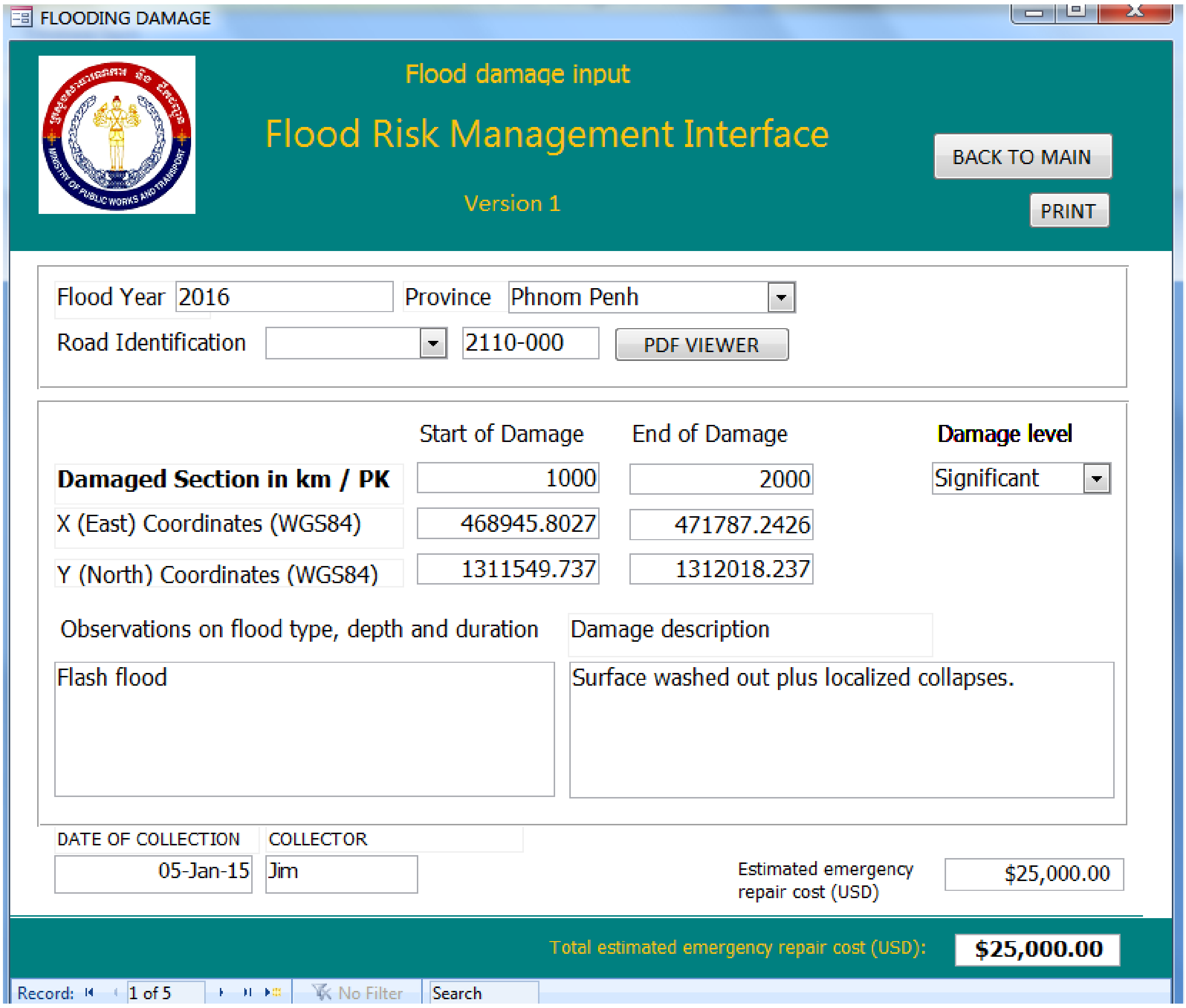


Figure 8 Flood damage data input

A typical mapping of flooded sections is shown below. The key inputs are the GPS coordinates of the damaged areas which can be inserted into the Arc GIS maps.

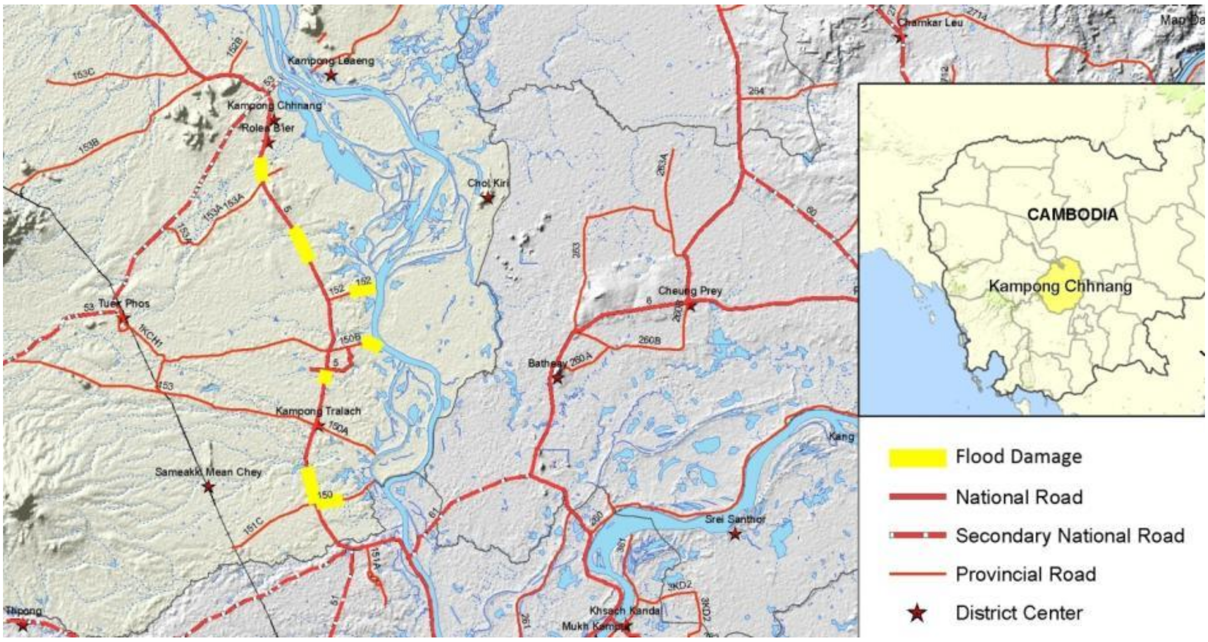


Figure 9 Road sections damaged by floods

Specific issues on flood damage data collection are further explained in Appendix 3.

5 Road Information and Rehabilitation costing scenarios

Road information

Basic road infrastructure data such as bridges, culverts and road alignments can be retrieved easily from the MPWT RAMS database. The RAMS data base has a solid operational base. There are about 550 individual road links on national and provincial level registered in the database, along with more than 13,000 bridges, culverts and other drainage related structures.

Various files from the RAMS dataset are used to update the road information in the Flood Risk Management Interface. These files can be updated by qualified RAMS operators.

All relevant road characteristics road condition data and drainage structures are stored in the database. Other information such as catchment areas or land use along the road can also be assessed quickly via the road information menu. The following road data is accessible directly from that menu:

- Geometric road parameters: Road Alignment, Length, vertical alignment of terrain, slopes
- Flood Risk Indices, with a link to 550 catchment area maps (Drainage AREA VIEWER)
- Inventory and condition of culverts and bridges for each road section (Drainage structures)
- Road condition (International roughness index: IRI RAMS)
- Land use
- Pavement type (Pavement surface)
- Recent major rehabilitation details (Recent rehabilitation data)

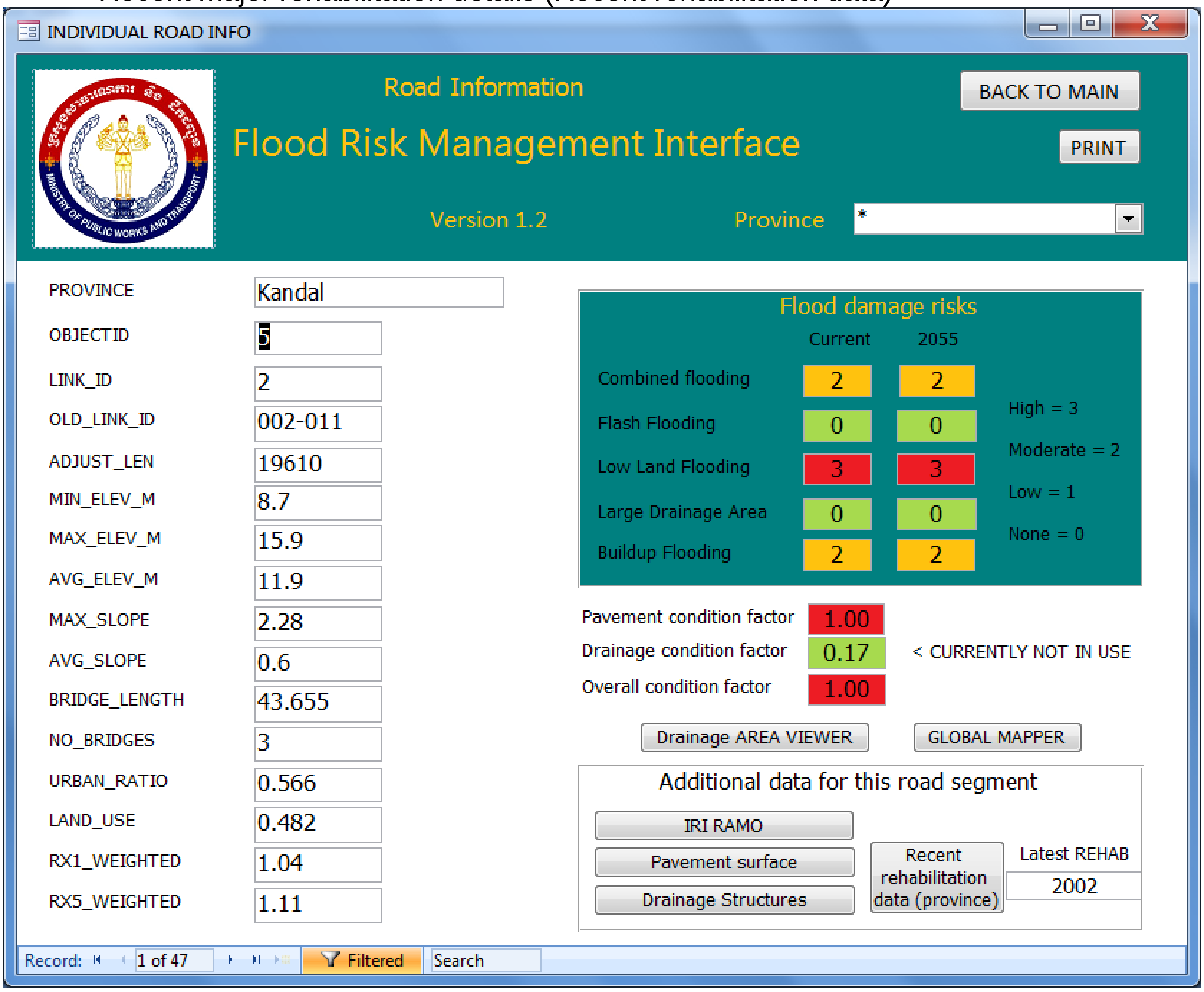


Figure 10 Road information

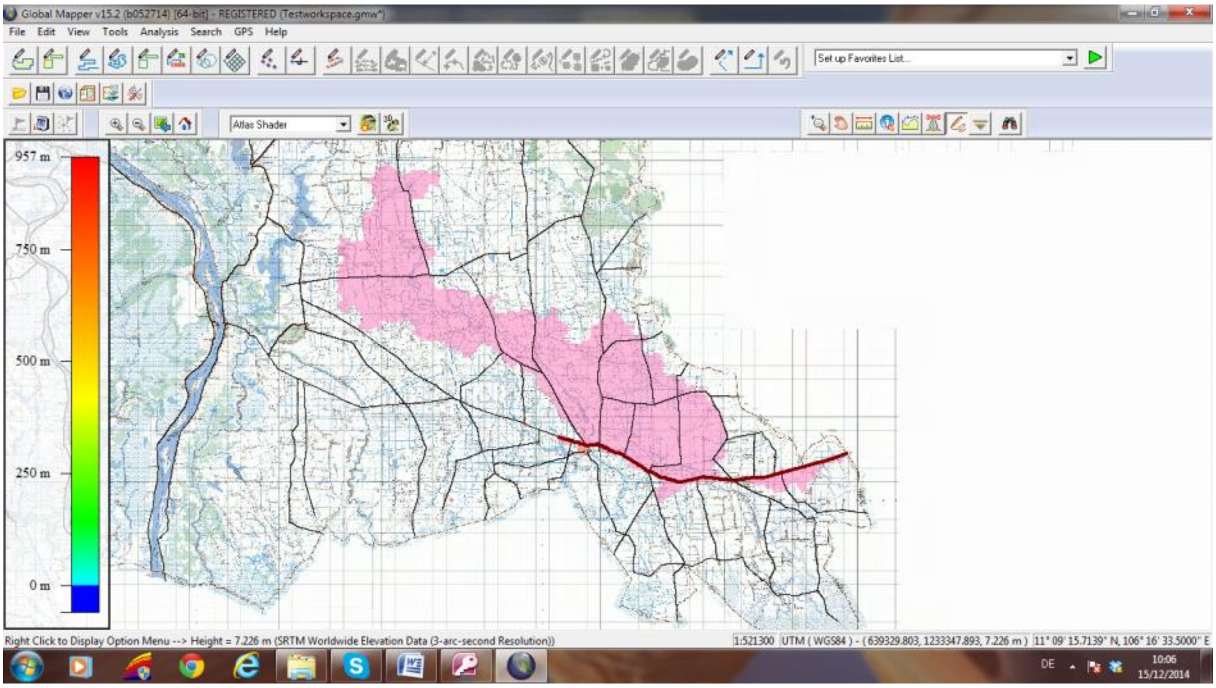
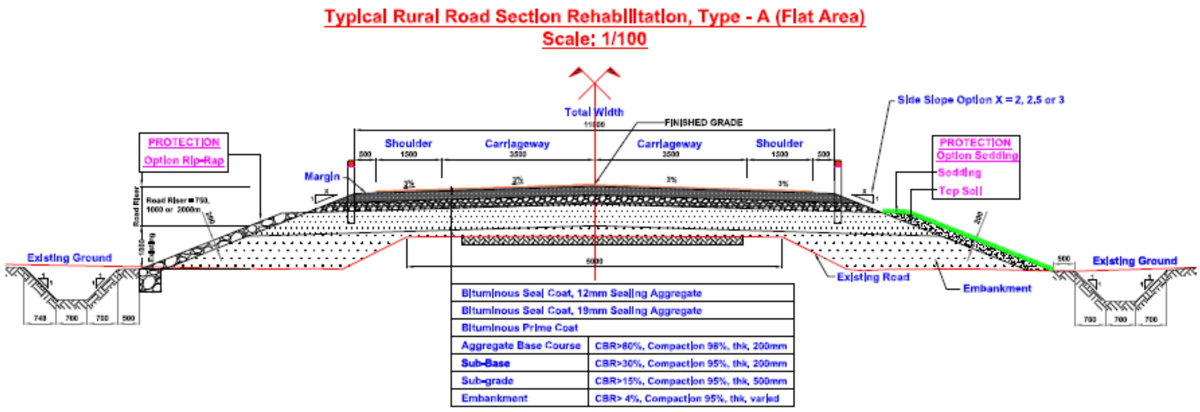


Figure 11 Road catchment (drainage) areas in GLOBAL MAPPER

Rehabilitation costing scenarios

A quick budgeting tool is available for conducting a preliminary estimation of flood proofing initiatives. Several road segments can be selected for rehabilitation and flood proofing measures such as road raising, replacement of culverts, adding embankment protection and using A/C pavements can be assigned to each of those segments. A number of combinations called scenarios can then be assessed and compared. The most interesting scenarios would then be further investigated through traditional design and analysis methods to confirm the scope of the interventions.

The simplified design models and options used by the budgeting tools are based on the most common rehabilitation designs used in Cambodia and are represented as follows:



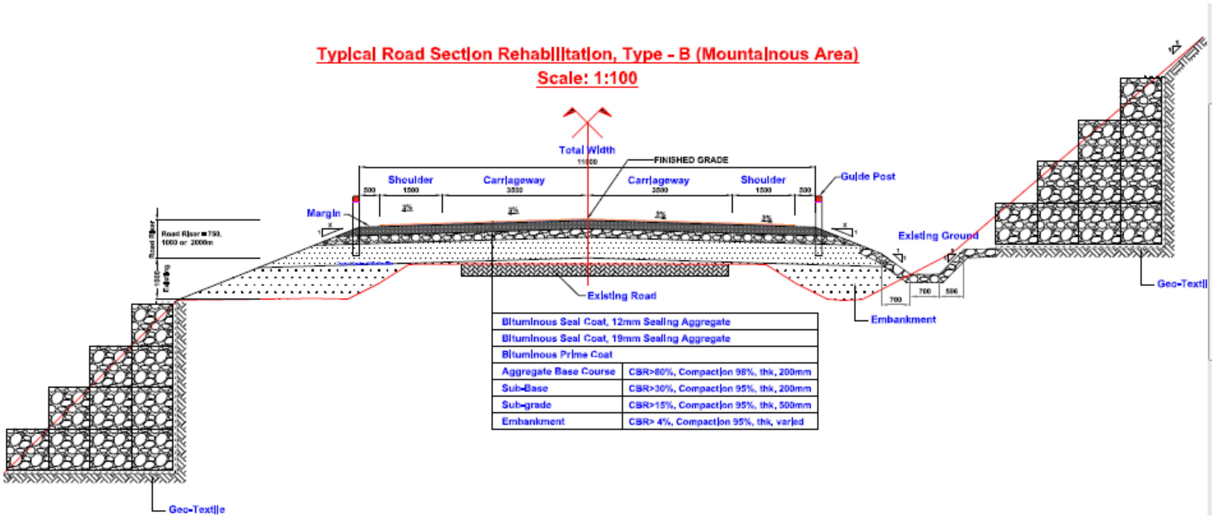


Figure 12 Simplified design models

All these designs assume an increase in the widening of the road from two lanes to four lanes, since roads selected for rehabilitation are usually those experiencing a significant increase in traffic and have a high socio-economic priority.

Options are provided for different upgrades as follows.

Table 2 Pavement upgrades

Pavement
Concrete 250 mm
A/C 50mm
A/C 40mm
A/C 30mm
DBST 20 mm

Table 3 Road rise

Road rise
0.75m (minimum)
1 m
2 m

Table 4 Embankment slopes and protection upgrades

Embankment slope & protection
Slope 1/ 2 - Rip Rap
Slope 1/ 2.5 - Rip Rap
Slope 1/ 3 - Rip Rap
Slope 1/ 2 - Sodding
Slope 1/ 2.5 - Sodding
Slope 1/ 3 - Sodding
Slope 1/ 1 – Mesh gabion (mountainous roads)
None (buildup areas)
Rip Rap: Dia 150 mm

Table 5 Drainage capacity upgrades

Drainage capacity upgrade
High transversal
Moderate transversal
Low transversal
High longitudinal (buildup areas)
Moderate longitudinal (buildup areas)

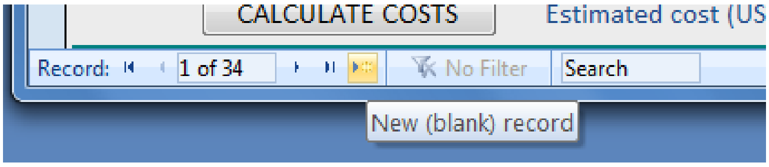
The detailed unit costs of these rehabilitations as well as guidelines for preliminary design are given in Appendix 5.

Figure 13 Rehabilitation costing tool

An important feature of the costing tool is the capacity to break down the design of a given section into any number of sub-sections (using separate records for different rehab lengths) to reflect local conditions and constraints.

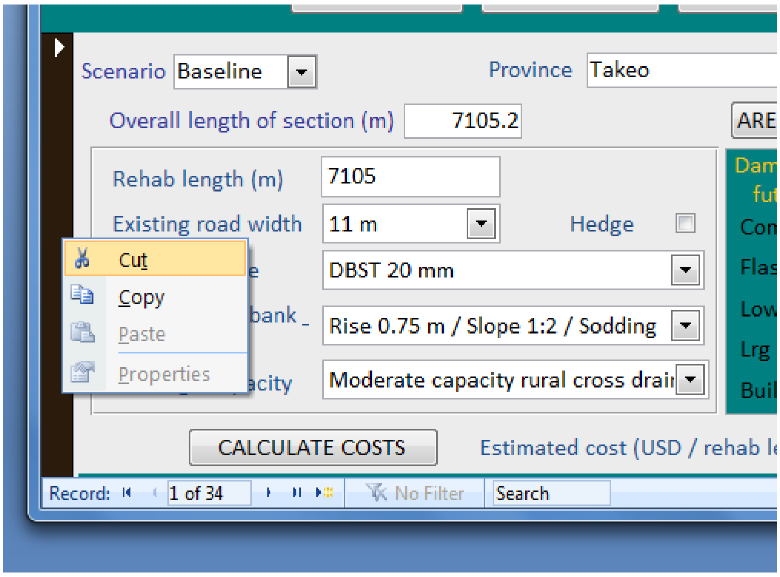
Adding a record

Click on the yellow star button on the bottom ribbon as shown below:



Deleting a record

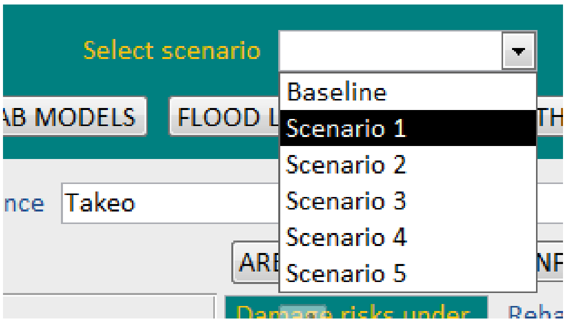
Right click on the black vertical bar on the left of the record and select Cut as shown below:



The application allows building up a baseline scenario for a given selection of road segments and up to 5 scenarios.

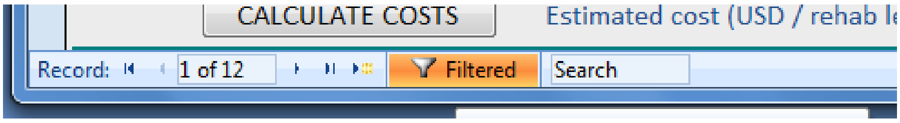
Filtering for a given scenario

Select the drop down button as shown below:



Removing the filter

Click on the orange filter button on the bottom ribbon as shown below:



6 E-library and help files

This module provides access to documents, help files and reports (including all CR-PRIP reports) relevant to flood proofing roads and climate resilience for the Cambodian context. New documents can be added and a category parameter facilitates their filtering.

The current document list is given in Appendix 6 and the documents have been included in the following categories:

- MRC reports and documents
- CR-PRIP reports
- Research papers and studies
- FRMI help files
- Flood proofing roads
- Cambodia road standards and specifications
- Reference flood maps

The topics of the documents are expected to expand and eventually cover more document types such as:

- ASEAN Road/Bridge design specification
- Test data from MPWT laboratory
- All development projects carries out by MPWT by donors, by year, by location etc.
- All reports and photo of all infrastructure studies
- Engineering related books in Khmer, English and French
- Soil type within kingdom of Cambodia
- Traffic information
- Road network
- Traffic management information
- Engineering related training

Figure 14 e-library

The following help files facilitate the updating of datasets, the insertion of new road segments, as well as software operations:

- How to update FRMI land use and urban ratio data
- How to insert new road segments into FRMI
- How to update FRMI pavement condition data
- How to update FRMI drainage structures condition data
- How to create future flood damage maps
- How to link ArcGIS with FRMI (at installation)
- Using Global Mapper
- How to build flood damage maps

They are detailed in Appendices 8 to 14.

7 Global Mapper capabilities

Global Mapper is particularly useful to facilitate road design checks and for developing new road alignment proposals.

Road Design Checks

In practical application the user would open the map link to an individual road section or road link and would then add the proposed design drawings as an overlay. Additional overlays such as satellite imagery, the result of drone investigations, GPS data from field visits etc. can also be added to the mapping window. The method requires that all overlays are geo-referenced and all drawings and topographical surveys have been carried out in accordance with national design standards, especially concerning the Map Datum and other standard parameters.

- Given the unlimited number of overlays which can be added to the map view the user can carry out a quick design check on the drawing. aspects, which can be quickly checked include:
- Location of bridges and culverts in the drawing
- Environmental aspects and buffer zones, including protection zones, cultural heritage sites etc..
- Issues of land acquisition, compensation and resettlement etc..

Road Design Alignment Proposal

Global Mapper software enables adding a number of background maps to the map window. The background maps can include a basic topographic map, a map layer of existing road links, an elevation model and a base layer of the hydrographic network.

The user can now digitize a new proposed road alignment onto the background map. The Global Mapper standard design tools such as those below can be used:

- Check of vertical terrain profile
- Estimation of cut and fill volumes
- Creation of provisional road stations (chainages)
- Measurements of lengths, slopes, areas etc..
- Export of designs to external applications, such as Google Earth etc..

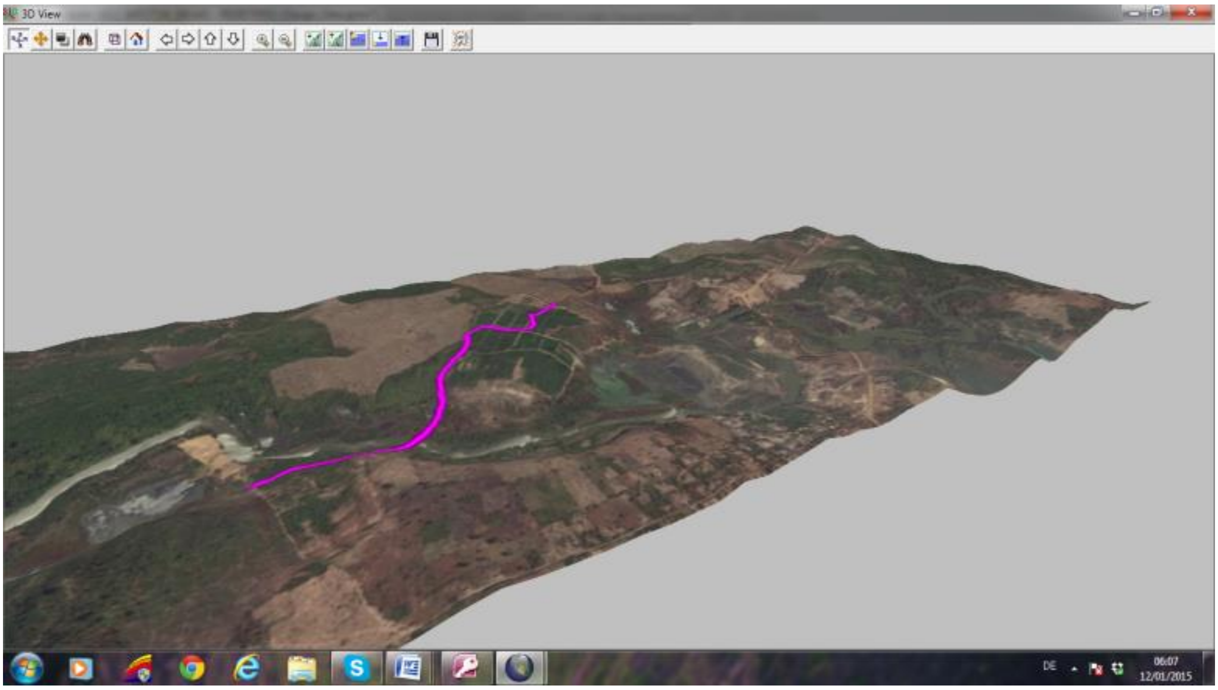


Figure 15 Road design capability

8 Interface limitations and expandability features

Limitations

The interface was designed for the main purposes of informing about flood risks on roads in view to facilitate the prioritization of road rehabilitation projects at the national and provincial level and to facilitate the flood proofing process.
The following limitations are important:

1) The interface predicts the risk of floods and associated damages on a road segment scale of 5 to 50 km and therefore is not designed to predict local flooding events of a few hundred meters due to local road profile collapsing or to local diversion of obstruction of flows from nearby obstacles.
2) The interface informs on the probability of a flood event or associated road damage but it doesnt provide dynamic flow modeling and related flood elevations. This is very complex and only possible by high resolution modeling of every road segment, a type of modeling that is time consuming and costly and which is recommended only for high risk roads, usually at the preliminary design stage using high resolution terrain modelling using DGPS or Drone surveying.
3) The interface is not a detailed design tool. All the information it provides complements the design requirements of the Cambodia road design standards who must be complied with.

Expandability features

The Flood risk management interface was designed within the requirements of the CR-PRIP but has the capacity to be expanded in the future. Key new functions or extension areas are:

- Increasing the coverage of MPWT RAMS and then:
    - Importing RAMS road condition and traffic data into the FRMI flood indexes and reconciling all road data links in the datasets of MPWT
    - Geo-referencing roads using RAMS survey devices and importing exact road elevations and embankment measurements into FRMI
- Merging flood damage data collection with existing RID processes
- Importing flood, rainfall and other relevant datasets from MRC, MOWRAM and MOE

9 Installation and data maintenance

9.1 System requirements

The system is currently not networked and is configured as follows:

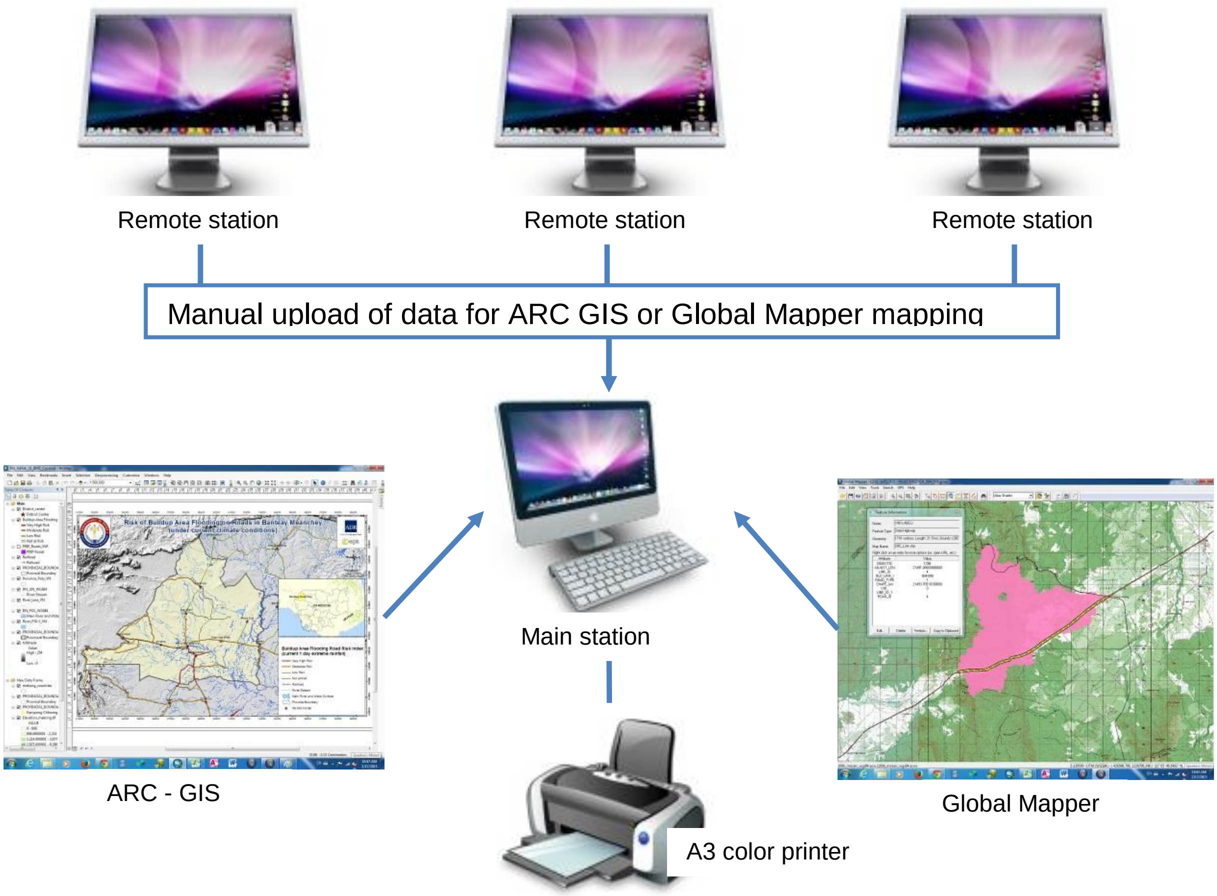


Figure 16 FRMI system configuration

The integration of the Flood Risk Management Interface in a Ministry wide network is highly recommended in the near future.

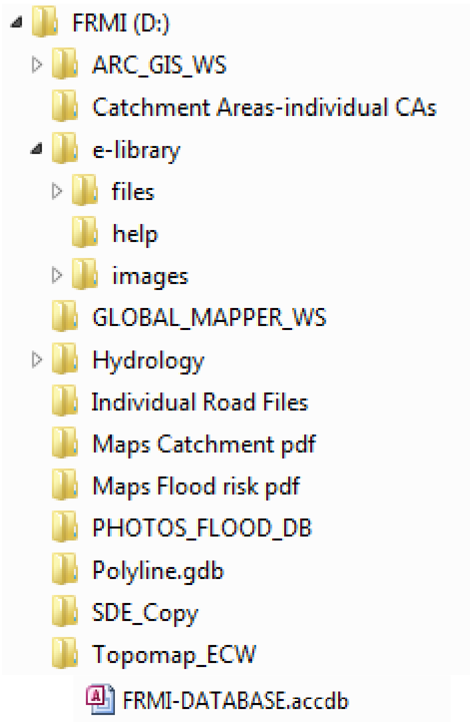
The minimum requirements are:

- Desktop computer 4 GB RAM, 500 GB HD, HD screen with graphic accelerator
- MS Office 2007 (runs on MS Access)
- Installed licenced versions of Global Mapper and Arc GIS for full functionality
- Color printer A3 size for best outputs

9.2 File structure and software installation

Folder structure

All working files including workspaces files for Global Mapper, ARC GIS, graphic maps or e-library must be installed under the FRMI folder as shown below.



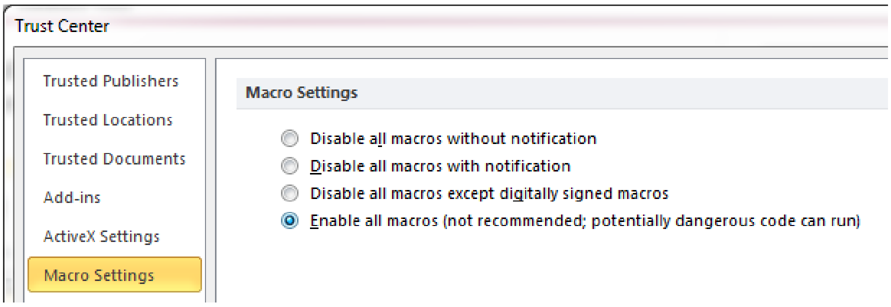
ARC GIS workspace files use Province named sub-folders while Global mapper files and JPG map files do not use it. Exact province code names used are given in Appendix 2.

Security

In order to operate FRMI smoothly, some security settings must be changed in MS Office as explained below.

➔ In FRMI, click on **File** in Tool Bar ➔ Click on **Info** ➔ Click on **Trust Center Setting** in **Security Warning Box**

➔ Click on **Macro Setting** in Trust Center Box ➔ Select **Enable all macros (not recommended; potentially dangerous code can run)** in Macro Setting Box ➔ Click on **O.K.**



Password changes

Open MS Office menu

Open FRMI-DATABASE with Open Exclusive

Development password is (case sensitive – use CAPS LOCK): MPWT

Important note: Due du current incompatibility issues in Arc GIS, the password must be removed on stations installed with Arc GIS to enable the automatic link between FRMI and Arc GIS.

Advanced Security

The database extension can be changed prior to distribution to provide enhanced security and smooth runtime operation for normal users.

Table 6 Advanced security settings

User type	Database extension
Normal users	.accdr
Database managers	.accdb

9.3 Data maintenance

The adequacy of the FRMI as a planning tool or as a guide for flood proofing roads is only as good as its data itself who must be updated regularly. Here is a table of recommended frequency updates for several types of data:

Table 7 Data maintenance recommendations

Data type	Recommended source	Recommended update frequency
IRI and pavement type	RAMS	Every year
Drainage structures condition	RAMS	Every year
Land use		Every 2 years
Urban ratio		Every 2 years
Road links	MPWT Survey dept	Every 2 years
Rainfall data	CSIRO or MOE	Every 5 years
Flood damage	DPWT (provinces)	Every major flood

Appendix 1

Flood damage modelling

In order to define flooding risk - and thus risk from climate change - of individual roads, every registered road link has been analyzed according to the flooding risks outlined in the following.

Four different flooding types have been defined as follows:

- Flash flood
- Large area flooding
- Urban flooding
- Tonle Sap, Mekong and lowland floods

Flood types and the method in which each road section had been checked against the occurrence of each type (the risk) is described below.

Type 1 - Flash Flood

In order to produce a reasonable flood risk analysis it is required to define the term 'Flash Flood`'. The US Weather Service (www.weather.gov) defines a flash flood as:

"A flood caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through river beds, urban streets, or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam."

The definition[2] indicated that the following conditions are to be fulfilled for the generation of a flash flood.

- High intensity rainfall
- High runoff coefficient i.e. low rate of protecting vegetation cover, especially forest
- Steep overall slope of the drainage area or nearby the target road corridor
- Generally limited catchment area size, as the flood-wave has to keep up over the entire flow Length towards the target road.

Developing a Flash Flood Index for the RAMS Road Network

The development of flash flood indices on the basis of catchment geometry is a fairly established practice. However, it is usually carried out for individual road sections. The systematic analysis of complete road networks is a more recent development.

P.-A. Versini, E. Gaume, and H. Andrieu (2009) have carried out a similar analysis for the Gard Region of France. Their overall result is that it is possible to define a flash flood risk assessment for specific road sections, even if data concerning the existing drainage structures is limited. It seems that the location, local slopes, elevation and other physical road parameters can be used to broadly generate a flash flood index, if the method is adjusted to local conditions.

As mentioned above, slope, land use, rainfall intensity and catchment geometrics are the most relevant parameters in the analysis. In classical hydrological analysis these considerations were used for the development of the Rational Method for the estimation of peak flow from a specific catchment area. However, these parameters can also be found in

[2] The definition also indicates that flash floods caused by non-natural events, such as the release of flood waters from reservoirs and the case of dam failures have to be taken into consideration. This is a situation occurring in Banteay Manchey due to release of water from Thailand dams. However, since it is localized and not climate related, it has not been incorporated in the model.

most other hydrological methods for peak flood estimation, such as the ORSTOM[3] (Rodier and Auvray, 1965) method or Unit hydrograph methods (see for example Linsley 1958).

Land use and catchment surface cover are critical parameters when assessing flash floods.

National Mapping Organizations (NMO) have produced a Global Land Cover (GLC) dataset. The data is a 1km (30 arc seconds) grid with 20 land cover items. The data were created by using MODIS data observed in 2003 (TERRA Satellite) with the cooperation of NMOs of the world in providing training data and validation. The classification is based on the Land Use System developed by the United Nations Food and Agriculture Organization (http://www.fao.org/climatechange/54270/en/). The GLC dataset of NMOs was used to derive runoff coefficients for Cambodia. The following land uses were converted to a land use factor for each drainage area:

Land Use	Factor (LU)
Urban	1
Agriculture / grassland	0.5
Forest	0.2

The average runoff coefficient was extracted for each road link catchment. For further analysis these factors can be extended or fine-tuned, or in the case of future analysis, updated to recent satellite imagery.

Total Rainfall Depth and Rainfall Intensities

High quality data on rainfall intensity for short term events (6 hrs or less) are difficult to obtain for the entire country area of Cambodia. However, it can be expected that change in rainfall intensity is reflected in 24 hour rainfall records and projections. For this reason the 1 day extreme rainfall dataset from the climate data from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Conformal Cubic Atmospheric Model (CCAM) regional climate model was used for the analysis of the flash flood risk.

The spatial resolution of the climatic data consists of cells of 20 x 20 km. Extreme 1 day and 5 day high resolution precipitation data for the entire country was used. The data represents the maximum rainfall output by the model for a 10 year period centered on 2005 (current) and 2055. The 1 day extreme rainfall represents the maximum output for a single day and the 5 day extreme rainfall represents the maximum output from events that lasted 5 consecutive days of >1mm rainfall.

For this analysis normalized rainfall data has been used. The average rainfall component over each catchment was extracted and converted to an integer between 1.0 and 2.2 as outlined below.

5 day extreme Rainfall (mm/day)	Factor (R5)	1 day extreme Rainfall (mm/day)	Factor (R1)
120	1	120	1
160	1.2	140	1.2
200	1.4	160	1.4
240	1.6	180	1.6
280	1.8	200	1.8
320	2	220	2
360	2.2	240	2.2

The following parameters were therefore used to define the flood risk of a road section due to Flash floods:

Parameter	Justification
Drainage area average Slope ***S*** in %	Steep slopes are required for flash flood development. In order to increase the weight of

[3] Office de la recherche scientifique et technique outre-mer

	the drainage-area-slope on the final Flash Flood Indicator, the **square of the average slope** was used in the calculation.
Road Length ***RL*** (m) / Drainage Area Perimeter **DAP** (m)	This indicator aims at describing the overall drainage area shape. A value close to 1 indicates that the drainage area does not extend far from the road alignment. Drainage areas with high values are thus small, with short time of concentration.
Land use factor ***LU***	Satellite imagery used as pointed out above
1 day extreme rainfall factor ***R1***	As pointed out above
Flash Flood Risk = **S**^2 x (**RL**(m) / **DAP**(m)) x **LU** x **R1**	

Type 2 - Large Area Flooding

The parameter is aimed at characterizing large drainage areas, which are drained by medium and large bridges. The key parameter for this index is the drainage area drained by 1 km of road, i.e. Area/Length. The indicator measures the 'hydraulic load' per km of road. If this value is high, bridges are required to provide adequate drainage capacity.

To further focus the analysis on the flooding of large catchment areas a bridge factor is used. The bridge factor quantifies the percentage of the road segment having large drainage structures. The resulting figure is multiplied with the land use coefficient (see above) and a weighted factor for total extreme 5 day rainfall.

Parameter	**Justification**
Hydraulic Load ***HL*** = Drainage area (km2) /Length (m)	This indicator aims at describing the overall drainage area shape. A high value indicates a large drainage area to be concentrated on a small section of road.
Bridge Factor ***BF***	A large factor indicates a large percentage of bridge length in the road Length
Land use factor ***LU***	Satellite imagery used as pointed out above
5 days extreme rainfall factor ***R5***	As pointed out above
Large Area Flooding Risk = **HL** x **BF** x **LU** x **R5**	

Type 3 - Urban Flooding

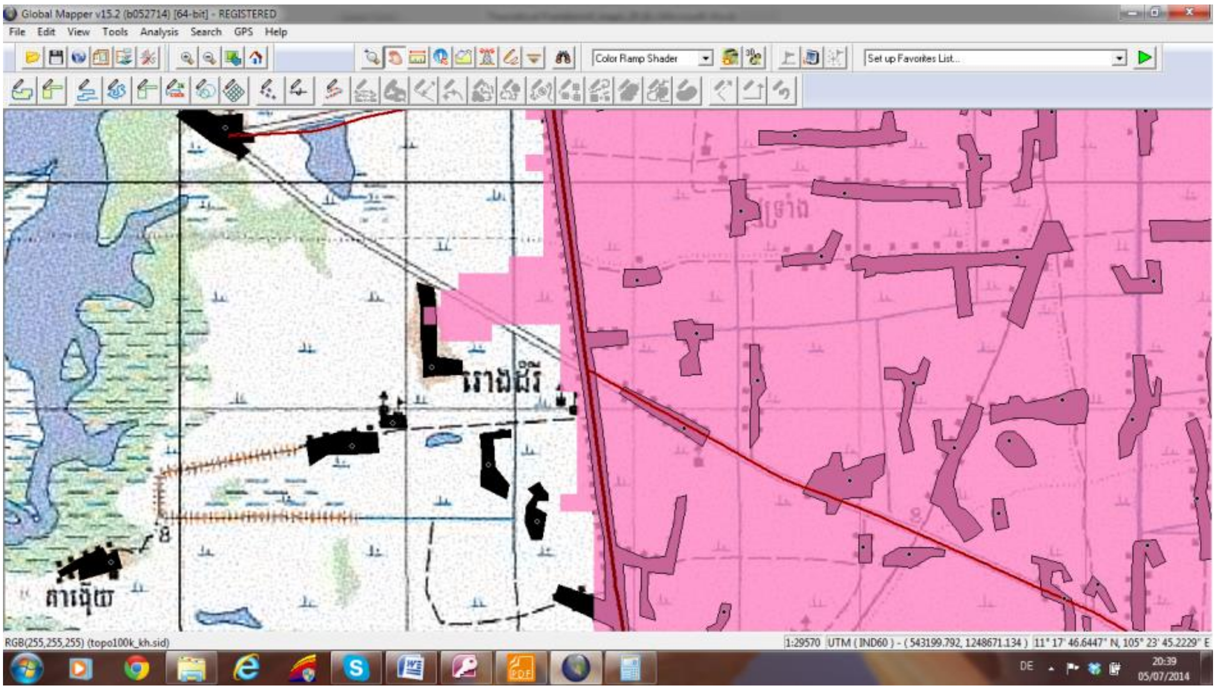
Urban drainage systems are designed according to national design standards. Drainage design is usually based upon Intensity Duration Frequency (IDF) curves for various regions, based upon detailed long term measurements of rainfall intensities.

However, the preparation of IDF curves require long term detailed measurements and the measurement network might not be dense enough to pick up climate change processes. A further aspect which makes built up areas susceptible to flooding is the dynamic of the urban areas. Private investment into individual housing and businesses is usually faster than the provision of road drainage structures, provided by public intervention. Planning and construction processes are slow and the construction of urban drainage usually runs behind the construction of houses, especially along transport links.

Urban areas are thus per se vulnerable to changes in rainfall intensities caused by climate change.

The measure for climate change vulnerability used for this analysis is the percentage of urban road in the entire road segment, multiplied with the 1 day extreme rainfall, obtained from the climate model used.

The analysis has been carried out on the basis of a population map available at the MPWT as part of a former project. Raster detection technology was applied to assess the extent to which every road passes through built - up environment. Values range from 0 % to 100% (e.g. all roads in Phnom Penh). The following figure illustrates the built - up area (in pink shading) around the urban section of Road 313-000.



It has to be pointed out that this factor is not a land use factor for the drainage area, but an indicator to measure the built-up area directly left and right of the road corridor.

Parameter	Justification
Urban Ratio ***UR***	Measures the flooding risk in urban area on the basis of urbanization rate per segment of road.
1 day extreme rainfall factor ***R1***	Short term rainfall extreme values are used to simulate correlation with high rainfall intensities
Urban Flooding Risk = **UR** x **R1**	

Type 4 - Tonle Sap and Lowland Flood

The fourth flood risk analyzed is the risk of flooding for low lying areas of Cambodia. This includes not only the areas close to Tonle Sap, but also the flat areas south of Phnom Penh. In order to assess in how far an individual road section can be subject to flooding the inverse of the product of the average road elevation and the average slope of the individual road section was used.

As lowland flooding is susceptible to long and extended rainfall events the five day rainfall data has been used as a further factor in quantifying the flooding risk for low lying roads.

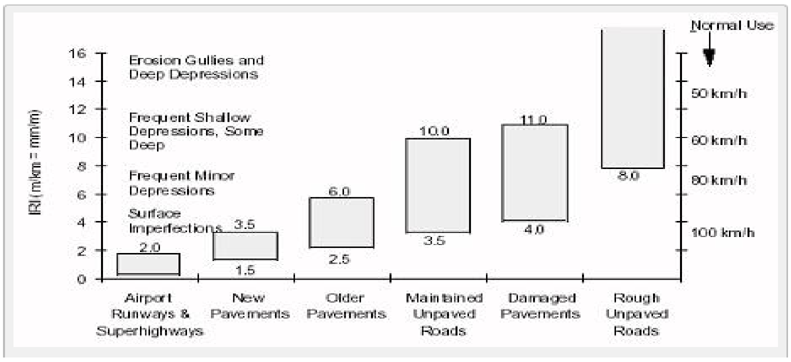
Parameter	Justification
Average road elevation ***HAVG***	Aimed at pointing out roads segments which are completely located in low areas.
Average slope of road ***SAVG***	As above
Total 5 day rainfall ***R5***	Indicator is sensitive to long term rainfall events
Low Land Flooding risk = **R5 / (HAVG** x **SAVG)**	

Road resilience

Vulnerable Cambodian roads are generally recognized as those who are poorly designed – i.e. not account for flood levels, poorly build – with poor material or compaction, and poorly maintained. The actual modeling of flood damage to a road can be rather complex due to the large number of factors and to the difficulty in measuring all these factors.

This is why, in a view to assess the resilience of Cambodian roads, the Consultant has proposed a model based on two key indicators, the road pavement surface condition and the drainage structures condition. From these two parameters, a road planner can obtain a relatively good view of the location of roads whose condition makes them vulnerable to floods, with aim to prioritize rehabilitation interventions.

Pavement condition

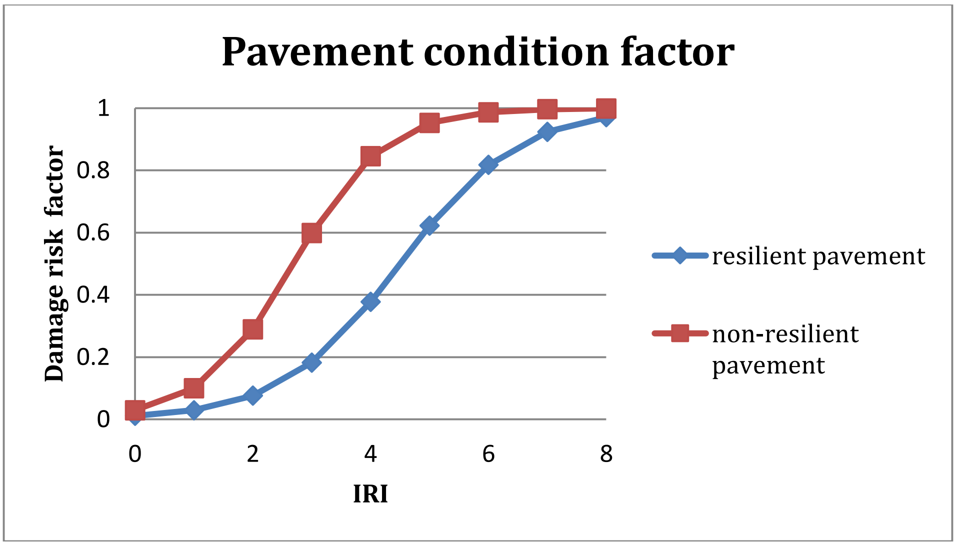


The overall road pavement surface condition is assessed using roughness condition (IRI), an indicator used by several donors. International roughness indexes inform on the irregularities of the road surface and can therefore inform on their vulnerability to water infiltrations and to rapid surface flow damage. The range of IRI conditions is represented in the following graph.

Next, the pavement type is retrieved from the MPWT RAMS data. To simplify the analysis, the pavement type is grouped as either resilient or non-resilient, in term of vulnerability to floods. Resilient types of pavements include asphalt concrete (AC) and concrete and non-resilient types include double base surface treated (DBST) roads, widely used in Cambodia or gravel roads.

Note: MPWT RAMS data for pavement types presently covers 80% of the network. Non-documented types are assumed as non-resilient.

The risk of flood damage on the road is therefore assessed using empirical curves build using pavement condition (IRI) and pavement type. These curves are however simple approximations of a complex deterioration phenomena and should only be used as indicators in a planning context.



The pavement condition factor therefore ranges from 0 for a perfect road to 1 to road sufficiently impaired to offer no resistance to floods.

Pavement condition factor	Value
As per graph above	0 (very good resilience to floods) to 1 (no resilience to floods)

Note: MPWT RAMS pavement condition data (IRI) covers presently about 70% of the National and Provincial road networks of the model. Non-documented IRI segments were assumed as 7.

Recently rehabilitated roads

Due to the age of the IRI inventory (one survey in 2011 and one survey in 2014), adjustments are made to account for a reduction in flooding risk following major and recent road construction projects. These recent rehabilitation projects, build under strict supervision arrangements and designed by international teams, are assumed to be build according to latest Cambodian road standards who require hydrological and hydraulic calculations for flooding.

However, due to the variety of design solutions in the projects, the risk of road damage due to flood was accounted for by setting the IRI to 1 for the corresponding road links.

For convenience, all roads under major construction contracts planned by MPWT to be completed within the duration of the Consultant mandate, i.e. 2017, have been recorded as rehabilitated.

Drainage structures condition

The MPWT owns a comprehensive inventory of road drainage structures with associated condition data. A set of factors are proposed to modelize the drainage capacity of a road segment to drain as per its design requirements. First the condition of each drainage structure of the data base, either a bridge or a culvert, is converted in a rating.

Individual drainage structure condition (as recorded from RAMS)	Rating (0 - good) to 1 - blocked)
Bridge - good	0
Bridge - poor	0.2
Bridge - broken	0.5 or as documented
Culvert - clear	0
Culvert - blocked	1
Culvert - collapsed	1

Then this rating is cumulated for all the drainage structures for the whole length of the road segment and averaged.

Drainage condition factor	Value
SUM of (rating * length of drainage structure) / (total length of drainage structures in road segment)	0 (excellent drainage) to 1 (ineffective drainage)

Road resilience

An overall road condition factor is build with a combination of pavement condition effects and drainage condition effects. Each factor is weighable to account for the quality and availability of data and for future calibration purposes.

Road condition factor	Value
PCW * Pavement condition factor + DCW * Drainage condition factor	0 (excellent condition) to 1 (very poor condition)

Where:

PCW = Pavement condition weight
DCW = Drainage condition weight = 1 - PCW

Important note: Given the age of drainage condition data available in the RAMS inventory (data from 2006), DCW was temporarily set to 0 for the flood risk damage maps.

Flood damage risk

The road damage risk is the flood risk reduced by the road resilience factor as shown below. For example, a road having low resilience will be fully exposed to the flood risk assessed for that road. If the flood risks happen to be low for a given type of flood (i.e. small catchment area, low extreme rainfall, etc…), the flood damage risk associated to that road will still be low.

Flood damage risk to road	Value
Flood risk * Road condition factor	0 (No risk) to 3 (High risk)

Appendix 2

Structure of map names

Risk of Buildup Area Flood damage on Roads in Kampong Chhnang (under current climate conditions)	Bld_FldRsk_KCH_Cur
Risk of Flash Flood damage on Roads in Svay Rieng (under future climate conditions)	Flsh_FldRsk_SVR_Fut
Risk of Large drainage area Flood damage on Roads in Kampot (under future climate conditions)	LrgA_FldRsk_KAM_Fut
Risk of Low Land Area Flood damage on Roads in Prey Veng (under current climate conditions)	LwLnd_FldRsk_PVG_Cur
Change in Risk of combined Flood damage on Roads in Cambodia (2015 - 2055)	Comb_FldRsk_Cam_Chng
Road links of Kampong Cham	Road_Link_ID_KPC

Province code names from Ministry of Interior are given in following table. Please note that codes used by other Ministries may differ.

Province names

Code	*Acronym*	Names	ឈ្មោះពេញ
	CAM	Cambodia	
1	BMC	Banteay Meanchey	បន្ទាយមានជ័យ
2	BAT	Battambang	បាត់ដំបង
3	KPC	Kampong Cham	កំពង់ចាម
4	KCH	Kampong Chhnang	កំពង់ឆ្នាំង
5	KSP	Kampong Speu	កំពង់ស្ពឺ
6	KPT	Kampong Thom	កំពង់ធំ
7	KAM	Kampot	កំពត
8	KDL	Kandal	កណ្ដាល
9	KKG	Koh Kong	កោះកុង
10	KRT	Kratie	ក្រចេះ
11	MKR	Mondulkiri	មណ្ឌលគិរី
12	PNP	Phnom Penh	ភ្នំពេញ
13	PVR	Preh Vihear	ព្រះវិហារ
14	PVG	Prey Veng	ព្រៃវែង
15	PUR	Pursat	ពោធិ៍សាត់
16	RAT	Rattanakiri	រតនៈគិរី
17	SRP	Siem Reap	សៀមរាប
18	SHV	Sihanoukville	ព្រះសីហនុ
19	STG	Stung Treng	ស្ទឹងត្រែង
20	SVR	Svay Rieng	ស្វាយរៀង
21	TAK	Takeo	តាកែវ
22	OMC	Otdar Meanchey	ឧត្ដរមានជ័យ
23	KEP	Kep	កែប
24	PLN	Pailin	ប៉ៃលិន
25	TKM	Tbong Khmum*	ត្បូងឃ្មុំ

* Province created on 31 December 2013 but not updated in MPWT reference maps and RAMS system.

Appendix 3

Flood damage considerations

Post flood related data has been made available to the PRIP - CR for the 2011 and the 2013 floods in hard copy. The reports were scanned in, translated and reformatted in order to use the observed flooding data as calibration data for the flood risk indices. However, the following issues were discovered with this flood report data:

- It was not possible to link the observed and reported data from the flood damage report to the RAMS data base with conventional data base links. This was due to the fact that different road identifiers, road names and no LINK IDs were used.
- Flood damage location was only not linkable to the existing road data base, but also not supported by other location tools such as GPS coordinates, which could have been linked to known locations and thus mapped.
- Flood damage investigations were carried out in a non - standardized form. Some data collectors concentrated on the issue of flooding, i.e. the incident of water overtopping or flooding the existing road surface. In the report one could find statements like: 'overtopped for 2 days over a length of 200m'.
- Others reported more on the associated damage, which could be observed as a result of the flooding, i.e. potholes, destroyed embankments and washed out bridge foundations. Both types of information are important, but from different points of view. While the flooding information is crucial for analyzing the hydrological causes and hydraulic consequences of the flooding event, the damage report focuses on the cost for rehabilitation.

Appendix 4

Database references

OBJECTID	There are ~ 550 road segments in the database	1
PROVINCE	From MPWT RAMS	Phnom Penh
ADJUST_LEN	From MPWT RAMS	5092
LINK_ID	From MPWT RAMS	1
OLD_LINK_ID	From MPWT RAMS	001-000
ROAD_TYPE	From MPWT RAMS	1
SHAPE_LEN	Length adjusted from GIS (m)	5081.2
OID	From MPWT RAMS	0
LINK_ID_1	From MPWT: still incomplete, RAMS data needs to be reconciled with MPWT GIS data	
ROAD_ID	From MPWT RAMS	1
MIN_ELEV_M	Road elevation From SRTM using GlobalMapper	12.6
MAX_ELEV_M	Road elevation From SRTM using GlobalMapper	21.3
AVG_ELEV_M	Road elevation From SRTM using GlobalMapper (HAVG)	17.3
MAX_SLOPE	Road slope From SRTM using GlobalMapper	2.57
AVG_SLOPE	Road slope From SRTM using GlobalMapper (SAVG)	0.72
BRIDGE_LENGTH	From MPWT RAMS	37.448
NO_BRIDGES	Number of bridges in segment from MPWT RAMS	2
BRIDGE_FACTOR	Calculated: Bridge length / Shape length	0.00736991
DA_MIN_ELEV_M	Drainage area From SRTM using GlobalMapper	7
DA_MAX_ELEV_M	Drainage area From SRTM using GlobalMapper	26
DA_AVG_ELEV_M	Drainage area From SRTM using GlobalMapper	17.508
DA_MAX_SLOPE	Drainage area From SRTM using GlobalMapper	7.72
DA_AVG_SLOPE	Drainage area From SRTM using GlobalMapper	1.97
DA_SURFACE_AR	Drainage area From SRTM using GlobalMapper (Drainage area)	2.09
DA_PERIMETER	Drainage area From SRTM using GlobalMapper (DAP)	14.51
LEN_DIV_DA_PERIMETER	Calculated drainage area dimension ratios (RL / DAP)	0.3502
AREA_DIV_LEN	Calculated drainage area dimension ratios (HL)	0.412
URBAN_RATIO	From fao.org using Global Mapper (UR)	1
LAND_USE	From fao.org using Global Mapper (LU)	0.471
RAINFALL	Annual current rainfall	1300
MAX_1_DAY_RAIN	From CSIRO CCAM model (RX1)	124.82
MAX_5_DAY_RAIN	From CSIRO CCAM model (R5)	150
MAX_1_DAY_2055	From CSIRO CCAM model	124.82
MAX_5_DAY_2055	From CSIRO CCAM model	147.5
RAIN_FALL_WEIGHT	Annual weighted	1
RX1_WEIGHTED	1 day current weighted	1.05
RX5_WEIGHTED	5 day current weighted	1
RX1_2055	1 day future weighted	1.05
RX5_2055	5 day future weighted	0.99
FF_INDEX	Calculated index Flash Flood Damage	0.672138543
LCA_INDEX	Calculated index Low Catchment area Flood Damage	0.001430146
UF_INDEX	Calculated index Urban Flood Damage	1.05
LLF_INDEX	Calculated index Lowland Flood Damage	80.28259473
FF_I	Calculated ranking Flash Flood Damage Current	0
LCA_I	Calculated ranking Low Catchment area Flood Damage Current	0
UF_I	Calculated ranking Urban Flood Damage Current	2

LLF_I	Calculated ranking Low Land Flood Damage Current	1
TOTAL_I	Sum ranking Combined Flood Damage Current	3
RISK_SCORE	Combined Flood Damage risk score (Total_I normalized)	1
FF_55	Calculated index Flash Flood Damage Future	0.672138543
LCA_55	Calculated index Low Catchment area Flood Damage Future	0.001415844
UF_55	Calculated index Urban Flood Damage Future	1.05
LLF_55	Calculated index Low Land Flood Damage Future	79.47976879
FF_55_I	Calculated ranking Flash Flood Damage Future	0
LCA_55_I	Calculated ranking Low Catchment area Flood Damage Future	0
UF_55_I	Calculated ranking Urban Flood Damage Future	2
LLF_55_I	Calculated ranking Low Land Flood Damage Future	1
TOTAL_I_55	Sum ranking Combined Flood Damage Current	3
RISK_SCORE_55	Combined Flood Damage risk score future (Total_I_55 normalized)	1
FF_DIFF	Difference Future - Current	0
LCA_DIFF	Difference Future - Current	0
UF_DIFF	Difference Future - Current	0
LLF_DIFF	Difference Future - Current	0
TOTAL_DIFF	Difference Future - Current	0
RISK_DIFF	Combined Flood Risk Score 55 - Risk Score	0
FF_I_chng		0
LCA_I_chng		0
UF_I_chng		0
LLF_I_chng		0
RISK_SCORE_chng		0

Thresholds used to convert index values into risk classes

Risk Class	GIS Value	Flash Flood	Large Catchment Area	Built Up Area	Low Land Flood	Risk Score (Combined)
No Risk	0	< 1	< 0.03	< 0.3	< 15	< 3
Low Risk	1	< 5	< 0.011	< 0.4	< 41	< 5
Moderate Risk	2	< 10	< 0.1	< 1	< 81	< 7
High Risk	3	≥ 10	≥ 0.1	≥ 1	≥ 81	≥ 7

Flood proofing Guidelines

	Flash				Low land (Mekong / Tonle sap)	
	FF		FF		LLF	LLF
Flood risk Risk level	High		Mod		High	Mod
Protection embankment	Rip rap	MeshGab	Hedge	MeshGab	Rip rap	Hedge
Embankment slope 1/X	2.5 or 2	1	2.5	1	2.5 or 2	2.5
Road rise (m)	0.75	0.75	0.75	0.75	As locally required – see map (0.75 min)	0.75
Pavement	AC or DBST	AC or DBST	DBST	DBST	AC or DBST	AC or DBST
Culverts or drainage capacity	High cross	High cross	Mod cross	Mod cross	Mod cross	Mod cross

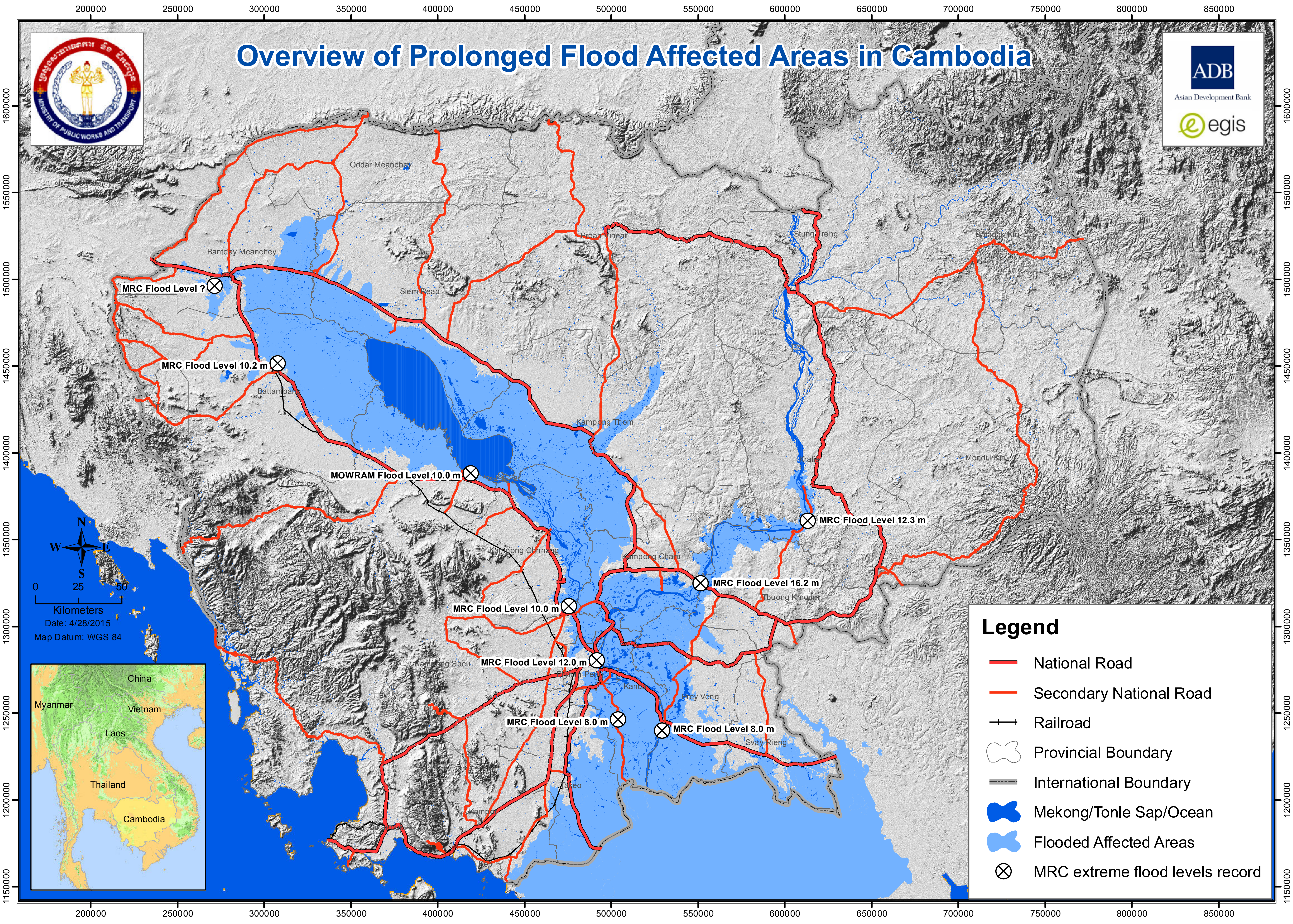
Flood risk Risk level	Highlands / large catchment		Buildup areas		Other	
	LCA	LCA	UF	UF		
	High	Mod	High	Mod	Low	None
Protection embankment	Hedge	Hedge	None	None	Sod	Sod
Embankment slope 1/X	2.5	2.5	None	None	2	2
Road rise (m)	0.75	0.75	None	None	None	None
Pavement	AC or DBST	DBST	AC or concrete	AC or concrete	DBST	DBST
Culverts or drainage capacity	High or Mod cross	Mod cross	High Longit	Mod Longit	Low cross	Low cross

Note: Options are given for two prevention levels.

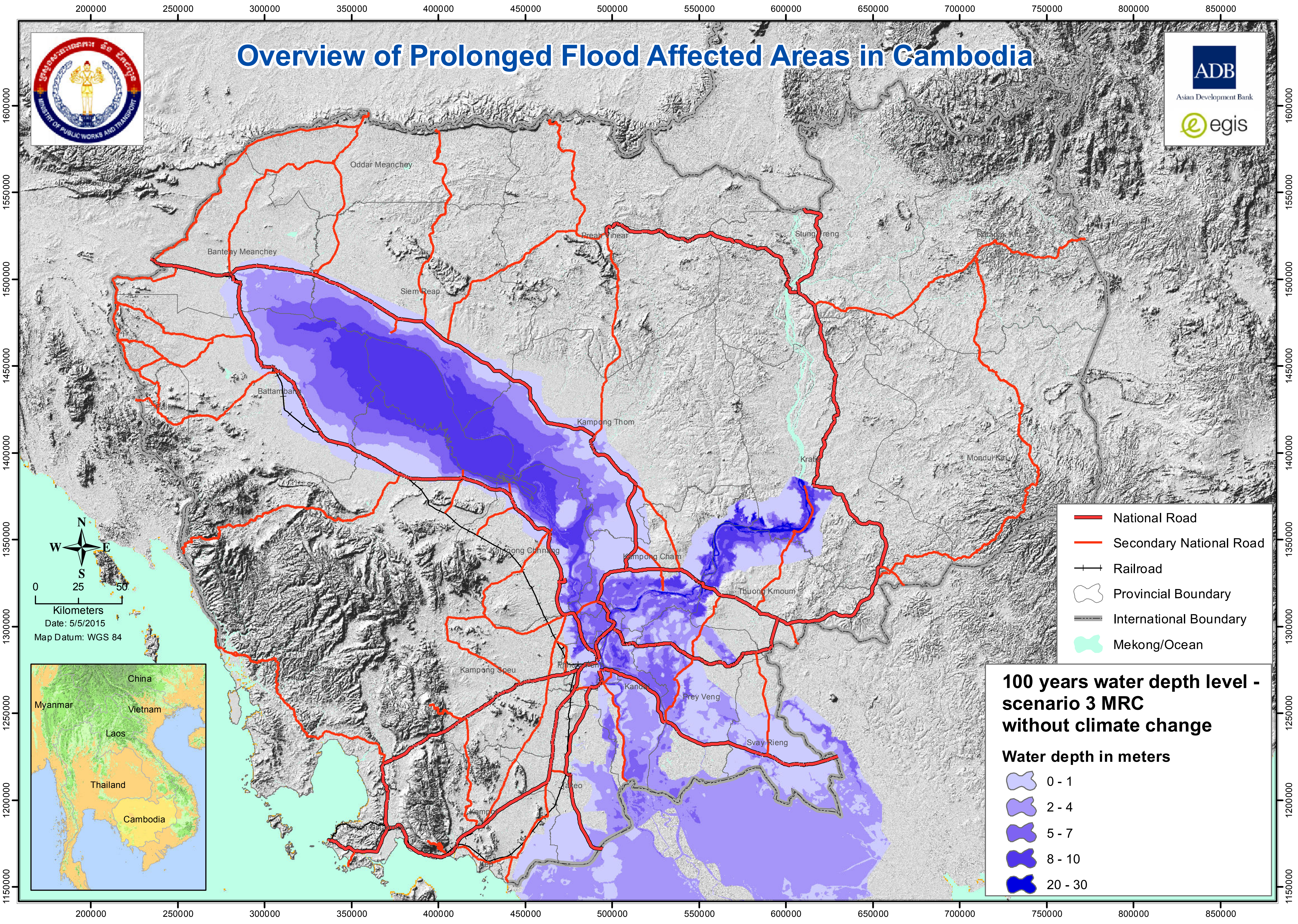
Unit costs table

Cost_type	Description	Unit_cost
Drainage	High capacity rural cross drainage	$3.70
Drainage	High capacity urban side drainage	$285.90
Drainage	Low capacity rural cross drainage	$1.24
Drainage	Moderate capacity rural cross drainage	$2.47
Drainage	Moderate capacity urban side drainage	$142.95
Geometry11m-11m	Rise 0 / repair to surface & sub base	$165.03
Geometry11m-11m	Rise 0.75 m / Slope 1:1 / Mesh Gabions	$1,551.04
Geometry11m-11m	Rise 0.75 m / Slope 1:2 / Rip Rap	$271.31
Geometry11m-11m	Rise 0.75 m / Slope 1:2 / Sodding	$160.10
Geometry11m-11m	Rise 0.75 m / Slope 1:2.5 / Rip Rap	$303.04
Geometry11m-11m	Rise 0.75 m / Slope 1:2.5 / Sodding	$173.01
Geometry11m-11m	Rise 0.75 m / Slope 1:3 / Rip Rap	$335.56
Geometry11m-11m	Rise 0.75 m / Slope 1:3 / Sodding	$186.16
Geometry11m-11m	Rise 1 m / Slope 1:2 / Rip Rap	$297.85
Geometry11m-11m	Rise 1 m / Slope 1:2 / Sodding	$177.42
Geometry11m-11m	Rise 1 m / Slope 1:2.5 / Rip Rap	$333.70
Geometry11m-11m	Rise 1 m / Slope 1:2.5 / Sodding	$192.54
Geometry11m-11m	Rise 1 m / Slope 1:3 / Rip Rap	$370.18
Geometry11m-11m	Rise 1 m / Slope 1:3 / Sodding	$207.75
Geometry11m-11m	Rise 2 m / Slope 1:2 / Rip Rap	$308.68
Geometry11m-11m	Rise 2 m / Slope 1:2 / Sodding	$184.56
Geometry11m-11m	Rise 2 m / Slope 1:2.5 / Rip Rap	$346.23
Geometry11m-11m	Rise 2 m / Slope 1:2.5 / Sodding	$200.66
Geometry11m-11m	Rise 2 m / Slope 1:3 / Rip Rap	$384.43
Geometry11m-11m	Rise 2 m / Slope 1:3 / Sodding	$216.79
Geometry5m-11m	Rise 0 / repair to surface & sub base	$165.03
Geometry5m-11m	Rise 0.75 m / Slope 1:1 / Mesh Gabions	$1,569.12
Geometry5m-11m	Rise 0.75 m / Slope 1:2 / Rip Rap	$289.40
Geometry5m-11m	Rise 0.75 m / Slope 1:2 / Sodding	$178.19
Geometry5m-11m	Rise 0.75 m / Slope 1:2.5 / Rip Rap	$321.13
Geometry5m-11m	Rise 0.75 m / Slope 1:2.5 / Sodding	$191.10
Geometry5m-11m	Rise 0.75 m / Slope 1:3 / Rip Rap	$353.65
Geometry5m-11m	Rise 0.75 m / Slope 1:3 / Sodding	$204.25
Geometry5m-11m	Rise 1 m / Slope 1:2 / Rip Rap	$315.94
Geometry5m-11m	Rise 1 m / Slope 1:2 / Sodding	$195.51
Geometry5m-11m	Rise 1 m / Slope 1:2.5 / Rip Rap	$351.79
Geometry5m-11m	Rise 1 m / Slope 1:2.5 / Sodding	$210.66
Geometry5m-11m	Rise 1 m / Slope 1:3 / Rip Rap	$388.27
Geometry5m-11m	Rise 1 m / Slope 1:3 / Sodding	$225.84
Geometry5m-11m	Rise 2 m / Slope 1:2 / Rip Rap	$326.77
Geometry5m-11m	Rise 2 m / Slope 1:2 / Sodding	$202.65
Geometry5m-11m	Rise 2 m / Slope 1:2.5 / Rip Rap	$364.32
Geometry5m-11m	Rise 2 m / Slope 1:2.5 / Sodding	$218.75
Geometry5m-11m	Rise 2 m / Slope 1:3 / Rip Rap	$402.52
Geometry5m-11m	Rise 2 m / Slope 1:3 / Sodding	$234.88

Cost_type	Description	Unit_cost
Hedge	Hedge	$9.60
Pavement	Asphalt concrete 30 mm	$78.66
Pavement	Asphalt concrete 40 mm	$102.41
Pavement	Asphalt concrete 50 mm	$126.16
Pavement	Concrete slab 250 mm	$531.55
Pavement	DBST 20 mm	$34.54



Overview of Prolonged Flood Affected Areas in Cambodia
MINISTRY OF PUBLIC WORKS AND TRANSPORT
ADB
Asian Development Bank
egis
Oddar Meanchey
Banteay Meanchey
Siem Reap
Preah Vihear
Stung Treng
Ratanak Kiri
Battambang
Kampong Thom
Kratie
Mondul Kiri
Kampong Chhnang
Kampong Cham
Tbuong Khmum
Kampong Speu
Kandal
Prey Veng
Svay Rieng
Takeo
MRC Flood Level ?
MRC Flood Level 10.2 m
MOWRAM Flood Level 10.0 m
MRC Flood Level 12.3 m
MRC Flood Level 16.2 m
MRC Flood Level 10.0 m
MRC Flood Level 12.0 m
MRC Flood Level 8.0 m
MRC Flood Level 8.0 m
N
W
E
S
0 25 50
Kilometers
Date: 4/28/2015
Map Datum: WGS 84
China
Myanmar
Vietnam
Laos
Thailand
Cambodia
Legend
National Road
Secondary National Road
Railroad
Provincial Boundary
International Boundary
Mekong/Tonle Sap/Ocean
Flooded Affected Areas
MRC extreme flood levels record



Overview of Prolonged Flood Affected Areas in Cambodia
MINISTRY OF PUBLIC WORKS AND TRANSPORT
ADB
Asian Development Bank
egis
Oddar Meanchey
Banteay Meanchey
Siem Reap
Preah Vihear
Stung Treng
Ratanak Kiri
Battambang
Kampong Thom
Kratie
Mondul Kiri
Kampong Chhnang
Kampong Cham
Thuong Kmoum
Kampong Speu
Kandal
Prey Veng
Svay Rieng
Takeo
N
W
E
S
0 25 50
Kilometers
Date: 5/5/2015
Map Datum: WGS 84
China
Myanmar
Vietnam
Laos
Thailand
Cambodia
National Road
Secondary National Road
Railroad
Provincial Boundary
International Boundary
Mekong/Ocean
100 years water depth level - scenario 3 MRC without climate change
Water depth in meters
0 - 1
2 - 4
5 - 7
8 - 10
20 - 30

Appendix 6

Category	Document title
MRC reports and documents	Roads and floods. Technical paper No 35
MRC reports and documents	Impacts of climate change and development on Mekong flow regimes First assessment - 2009. Technical paper No 29
CR-PRIP reports	Climate modeling report
CR-PRIP reports	Vulnerability mapping report
CR-PRIP reports	Knowledge management report
CR-PRIP reports	Road design standards changes
CR-PRIP reports	Ecosystem restoration report
CR-PRIP reports	Reinforcing community flood resilience
CR-PRIP reports	Concept of operation for emergency operation center
CR-PRIP reports	Standard operating procedures for emergency response to floods
CR-PRIP reports	Emergency warning system summary concept
Research papers and studies	Assessment of the susceptibility of roads to flooding based on geographical information.
FRMI help files	Flood Risk Management Interface manual
FRMI help files	How to update FRMI land use and urban ratio data
FRMI help files	How to insert new road segments into FRMI
FRMI help files	How to update FRMI pavement condition data
FRMI help files	How to update FRMI drainage structures condition data
Flood proofing roads	TRL Overseas road note 31: A guide to structural design of bitumen-surfaced roads in tropical and sub-tropical countries
Flood proofing roads	TRL Overseas road note 20: Management of rural road networks
Flood proofing roads	TRL Overseas road note 1: Road maintenance management for district engineers
Flood proofing roads	TRL Overseas road note 19: Guide to the design of hot mix asphalt in tropical and sub-tropical countries
Cambodia road standards and specifications	Part 1: Geometry
Cambodia road standards and specifications	Part 2: Pavement
Cambodia road standards and specifications	Part 3: Drainage
Cambodia road standards and specifications	Bridge design standard
Cambodia road standards and specifications	Construction specifications section 1
Cambodia road standards and specifications	Construction specifications section 2
Cambodia road standards and specifications	Construction specifications section 3
Cambodia road standards and specifications	Construction specifications section 4
Cambodia road standards and specifications	Construction specifications section 5
Cambodia road standards and specifications	Construction specifications section 6
Cambodia road standards and specifications	Construction specifications section 7
Cambodia road standards and specifications	Construction specifications section 8
Cambodia road standards and specifications	Construction specifications section 9
Cambodia road standards and specifications	Construction specifications section 10
Cambodia road standards and specifications	Construction specifications section 11
Reference flood maps	Dartmouth Flood Observatory: Cambodia flood 2000
Reference flood maps	WFP: Cambodia floods 2011 and 2013
FRMI help files	Using Global Mapper
FRMI help files	Instructions to link ArcGIS with FRMI
FRMI help files	Instructions to build ArcGIS flood damage maps
Reference flood maps	Extreme floods levels recorded by MRC in Cambodia
FRMI help files	Sample rehabilitation diagrams

Appendix 7

Flood Risk Statistics

Flood Risk Management Interface

Version 0.82

Province: Cambodia

Flood type: Combined flood

Risk level: High

Climate scenario: Current

OBJECTID	PROVINCE	LINK_ID	OLD_LINK_ID	ROAD_ID	Length of road (m)
13	Takeo	3	003-075	3	7105.2
16	Kampot	3	003-148	3	7901
18	Preah Sihanouk	3	003-180	3	21464.7
76	Kandal	21	021-000	21	34279.2
78	Kandal	1KD1-000	021A-000	1KD1	20092.2
80	Takeo	22	022-000	22	9630.7
85	Kep	33	033-015	33	3434.1
88	Kep	1330-000	033A-000	1330	19259.1
90	Preah Sihanouk	45	041-000	45	9284
102	Kandal	41	051-038	41	6848.1
154	Ratanak Kiri	3785-035	078B-035	3785	401
155	Svay Rieng	319-000	1000-000	319	13191.6
156	Svay Rieng	314-000	1001-000	314	10996.2
157	Svay Rieng	314B-000	1002-000	314B	14842.2
158	Svay Rieng	3SR6-000	1003-000	3SR6	14659.2
160	Svay Rieng	316-000	1005-000	316	13160.9
161	Svay Rieng	316A-000	1006-000	316A	14300.6
164	Kandal	118A-000	101-000	118A	10748.8
165	Kandal	118A-011	101-011	118A	31832.9
174	Kampong Cham	270-000	1017-041	270	22810.8
177	Kampong Cham	263-000	1019-000	263	22699
182	Kampong Cham	370-000	1026-000	370	16259.5
204	Takeo	122-000	106-000	122	13799.5
205	Takeo	121-000	106-013	121	8905.6
206	Takeo	127-000	107-000	127	4412.7

208	Takeo	1TK2-000	109-000	1TK2	1775
211	Takeo	1TK4-000	2003-000	1TK4	28323.9
215	Kampot	1313-000	116-000	1313	3704.5
231	Kampot	138-000	121-000	138	9998.5
241	Kandal	151-000	130-000	151	12003.2
246	Kandal	151A-000-D	134-000-D	151A	1919.5
260	Pursat	154-000	147-000	154	26805.2
261	Pursat	155B-000	148-000	155B	43512.8
265	Battambang	154G-000	149-000	154G	13132.9
266	Battambang	157-000	150-000	157	26770.2
272	Battambang	157C-000	155-000	157C	16954.4
275	Battambang	159B-000	157-000	159B	56849.4
277	Banteay Meanch	156D-000	158-000	156D	11252.8
279	Banteay Meanch	156C-000	160-000	156C	22220.8
280	Koh Kong	1481-000	161-000	1481	5323.3
282	Kandal	1210-000	2001-000	1210	7616.7
284	Kandal	112-000	2003-000	112	7844.7
290	Takeo	128C-028	2008-000	150A	13992.7
293	Takeo	129B-000	2010-000	129B	2226.7
296	Takeo	124-000	2013-000	124	10214.2
303	Kandal	380-003-D	2019-003-D	380	882.5
310	Kampot	1331-000	2026-000	1331	6416.9
317	Kandal	382-000	2032-000	382	13237.8
321	Kampot	132B-000	2036-000	132B	10486
322	Kampot	1311-000	2037-000	1311	14286.8
341	Siem Reap	267-000	2057-000	267	20558.5
351	Kampong Thom	2622-031	2066-031	2622	23939.6
354	Kampong Thom	265-000	2070-000	265	7582.6
357	Battambang	156B-000	2074-000	156B	6380.2
368	Battambang	159A-000	2083-000	159A	6413.6
369	Battambang	155G-000	2084-000	155G	23395.3
371	Pursat	154F-000	2086-000	154F	11238.7
378	Pursat	154B-000	2092-000	154B	15579.5
389	Koh Kong	48	048-000	48	49013.2

391	Pursat	152D-000	2103-000	152D	6806.1
401	Kampot	1311A-000	2112-000	1311A	9675.6
413	Kep	1KP1-000	2200-000	1KP1	1204.8
446	Prey Veng	311-000	318-000	311	8440.8
455	Svay Rieng	312C-000	329-000	312C	21042.9
462	Svay Rieng	316B-000	339-000	316B	17127
875	Svay Rieng	313B-000	321-000	313B	11085.8
878	Svay Rieng	314C-011	334-011	314C	8965.6
1319	Siem Reap	6	006-218	6	16975.6
1328	Takeo	31	031-000	31	4824.1
1330	Kep	33	033-000	33	12549.5
1338	Preah Vihear	62	064-029	62	12312.4
1360	Prey Veng	3PV1-000	1016-000	3PV1	32305
1363	Prey Veng	3SR7-018	1201-014	3SR7	3360.8
1364	Prey Veng	3PV2-000	1205-000	3PV2	29655.2
1385	Kandal	3KD2-003	2030-000	3KD2	9518.5
1387	Takeo	128C-012	113-000	128C	14543.8
1388	Pailin	1591-000	2082-000	1591	44684.7
1391	Kampong Cham	260-004	1017-000	260	36557.8
1404	Kampong Cham	3113-000	1041-000	3113	14022.3
1408	Kampong Cham	371-000	308-000	371	75441.3
1409	Kampong Cham	371-075	308-000	371	14092.8
1420	Prey Veng	3SR5-004	320-012	3SR5	8398.4
1421	Prey Veng	3SR5-012	320-012	3SR5	9860.2
1425	Kandal	8	2018-000	8	21562.4
				Total length (km)	**1,329.2**

Rehabilitation Costing

Flood Risk Management Interface

#Name?

Scenario Baseline | Province Takeo | Select Road ID 13 | 003-075

Overall length of section (m) 7105.2

		Damage risks under future conditions	
Rehab length (m)	7105	Combined	3
Existing road width	11 m	Flash:	0
Hedge	☐		
Pavement type	DBST 20 mm	Low land:	3
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding	Lrg drainage	3
Drainage capacity	Moderate capacity rural cross draina	Buildup:	2

Rehab note

Estimated cost (USD / rehab length) $1,528,996

Scenario Baseline | Province Kampot | Select Road ID 16 | 003-148

Overall length of section (m) 7901

		Damage risks under future conditions	
Rehab length (m)	7901	Combined	3
Existing road width	11 m	Flash:	0
Hedge	☐		
Pavement type	DBST 20 mm	Low land:	2
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding	Lrg drainage	3
Drainage capacity	Moderate capacity rural cross draina	Buildup:	2

Rehab note

Estimated cost (USD / rehab length) $1,700,295

Scenario Baseline | Province Preah Sihanouk | Select Road ID 18 | 003-180

Overall length of section (m) 21464.7

		Damage risks under future conditions	
Rehab length (m)	21464	Combined	3
Existing road width	11 m	Flash:	2
Hedge	☐		
Pavement type	DBST 20 mm	Low land:	3
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding	Lrg drainage	3
Drainage capacity	Moderate capacity rural cross draina	Buildup:	2

Rehab note

Estimated cost (USD / rehab length) $4,619,053

FOR ESTIMATION ONLY
See sample rehab models for details and assumptions

Sum of estimated costs (USD) **$40,369,689**

Sum of rehab length (km) **1870.03**

Rehabilitation Costing

Flood Risk Management Interface

#Name?

Scenario Baseline | Province Svay Rieng | Select Road ID 155 | 1000-000

Overall length of section (m) 13191.6

Rehab length (m)	13192		
Existing road width	5 m	Hedge	☑
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	0
Low land:	2
Lrg drainage	3
Buildup:	2

Rehab note

Estimated cost (USD / rehab length) $2,965,562

Scenario Baseline | Province Kampong Cham | Select Road ID 177 | 1019-000

Overall length of section (m) 22699

Rehab length (m)	22699		
Existing road width	5 m	Hedge	☐
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	0
Low land:	2
Lrg drainage	3
Buildup:	2

Rehab note

Estimated cost (USD / rehab length) $4,884,825

Scenario Baseline | Province Kampong Speu | Select Road ID 238 | 126-008

Overall length of section (m) 16815.1

Rehab length (m)	16815		
Existing road width	5 m	Hedge	☐
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	3
Low land:	2
Lrg drainage	1
Buildup:	1

Rehab note

Estimated cost (USD / rehab length) $3,618,588

FOR ESTIMATION ONLY
See sample rehab models for details and assumptions

Sum of estimated costs (USD) **$40,369,689**

Sum of rehab length (km) **1870.03**

Rehabilitation Costing

Flood Risk Management Interface

#Name?

Scenario: Baseline | Province: Pursat | Select Road ID: 261 | 148-000

Overall length of section (m): 43512.8

Rehab length (m)	43513		
Existing road width	5 m	Hedge	☐
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	1
Low land:	2
Lrg drainage	2
Buildup:	2

Rehab note

Estimated cost (USD / rehab length): $9,363,998

Scenario: Baseline | Province: Battambang | Select Road ID: 266 | 150-000

Overall length of section (m): 26770.2

Rehab length (m)	26770		
Existing road width	5 m	Hedge	☐
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	0
Low land:	2
Lrg drainage	3
Buildup:	2

Rehab note

Estimated cost (USD / rehab length): $5,760,904

Scenario: Baseline | Province: Banteay Meanchey | Select Road ID: 279 | 160-000

Overall length of section (m): 22220.8

Rehab length (m)	22221		
Existing road width	5 m	Hedge	☐
Pavement type	DBST 20 mm		
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding		
Drainage capacity	Moderate capacity rural cross draina		

Damage risks under future conditions	
Combined	3
Flash:	0
Low land:	2
Lrg drainage	3
Buildup:	2

Rehab note

Estimated cost (USD / rehab length): $4,781,959

FOR ESTIMATION ONLY
See sample rehab models for details and assumptions

Sum of estimated costs (USD): **$40,369,689**

Sum of rehab length (km): **1870.03**

Rehabilitation Costing

Flood Risk Management Interface

#Name?

Scenario	Baseline	Province	Koh Kong	Select Road ID	280 / 161-000

Overall length of section (m): 5323.3

Rehab length (m)	5323
Existing road width	5 m
Hedge	☐
Pavement type	DBST 20 mm
Road rise, embank protection	Rise 0.75 m / Slope 1:2 / Sodding
Drainage capacity	Moderate capacity rural cross draina

Damage risks under future conditions	
Combined	3
Flash:	2
Low land:	2
Lrg drainage	3
Buildup:	2

Rehab note

Estimated cost (USD / rehab length): $1,145,510

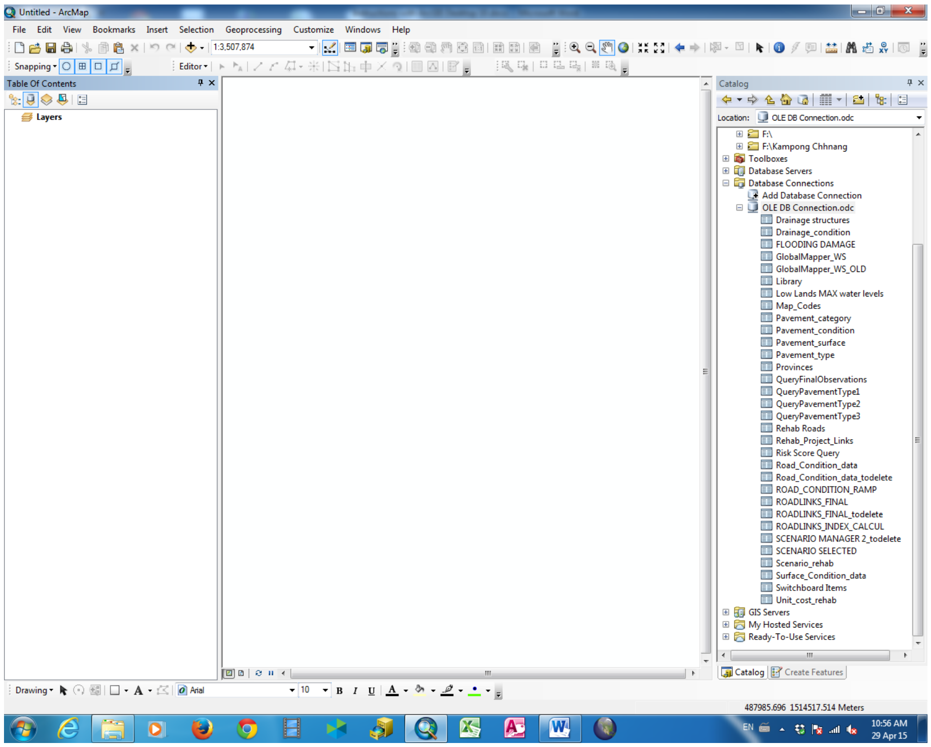
FOR ESTIMATION ONLY
See sample rehab models for details and assumptions

Sum of estimated costs (USD)	**$40,369,689**
Sum of rehab length (km)	**1870.03**

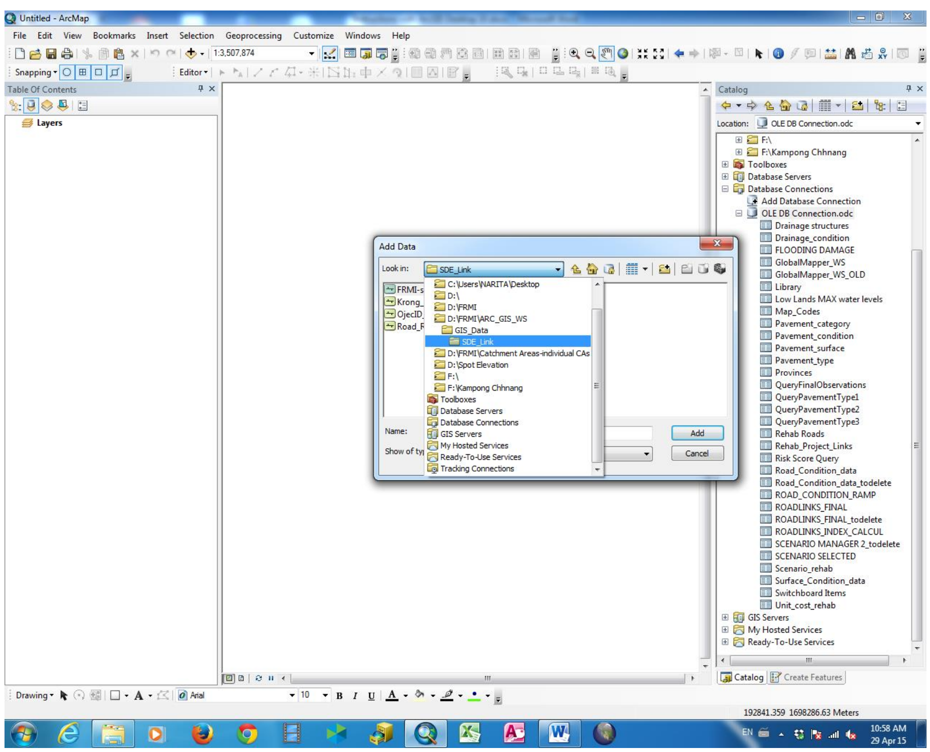
Appendix 8

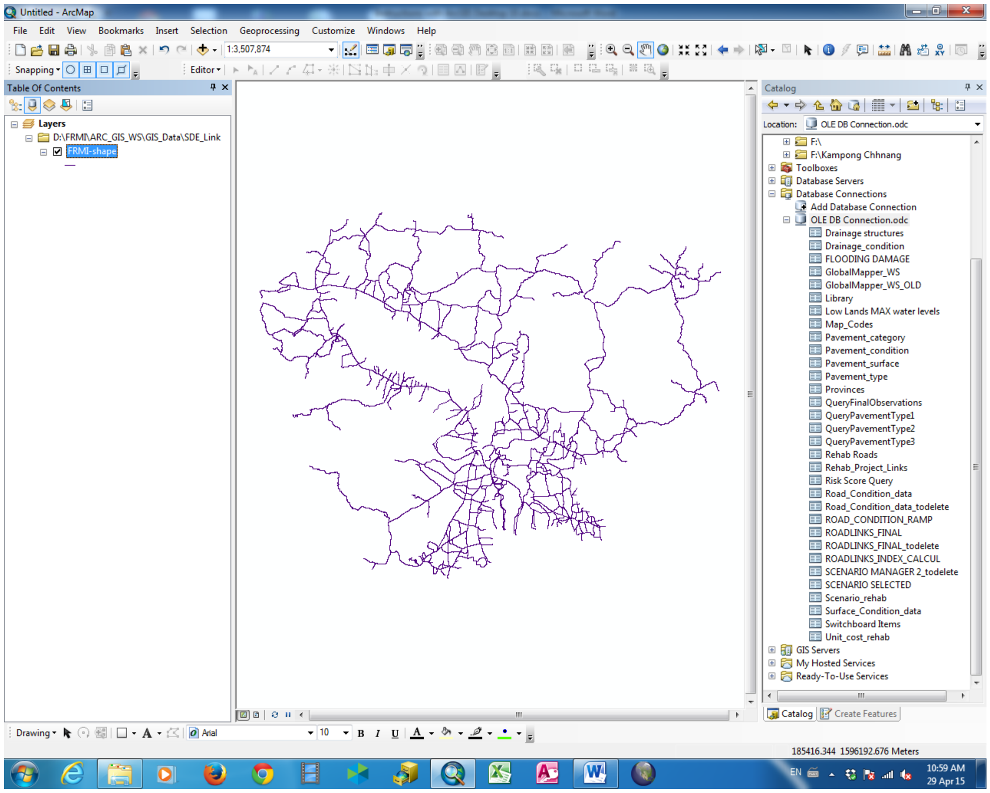
1. **<u>How to create for linking ArcGIS Desktop to the flood risk management interface from FRMI</u>**

- **<u>Open ArcGIS Desktop>Open ArcCatalog>OLE DB Connection.odc>Connect</u>**

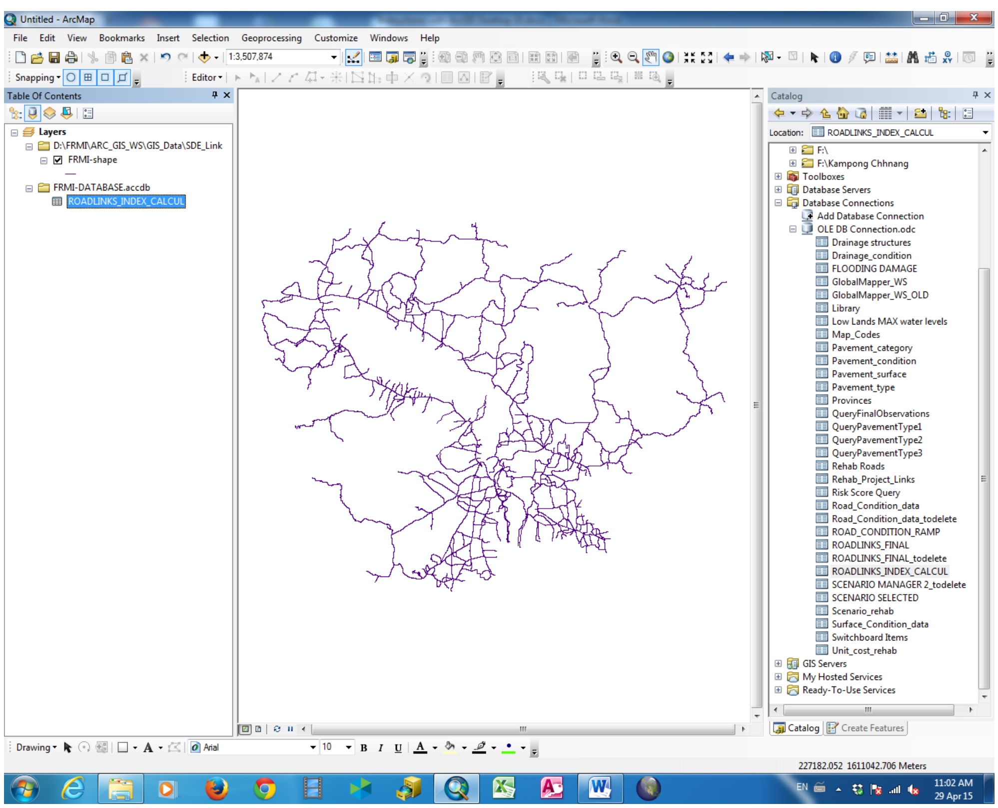


- **<u>Add shapefile of FRMI-Shape by adding</u>**

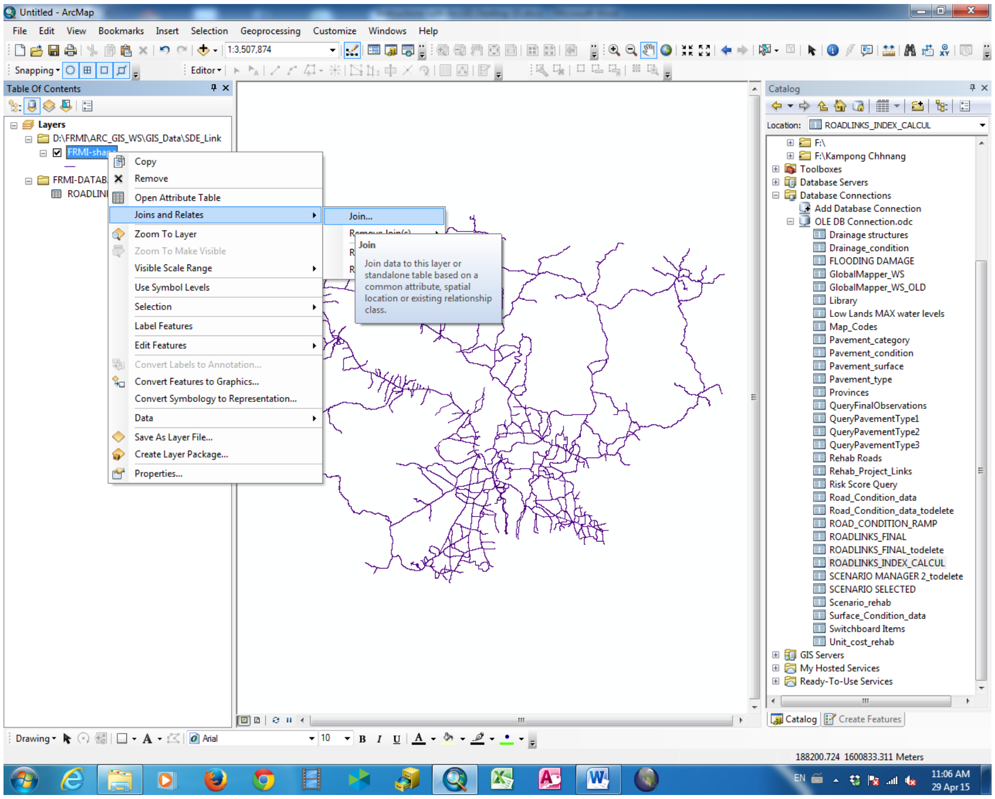


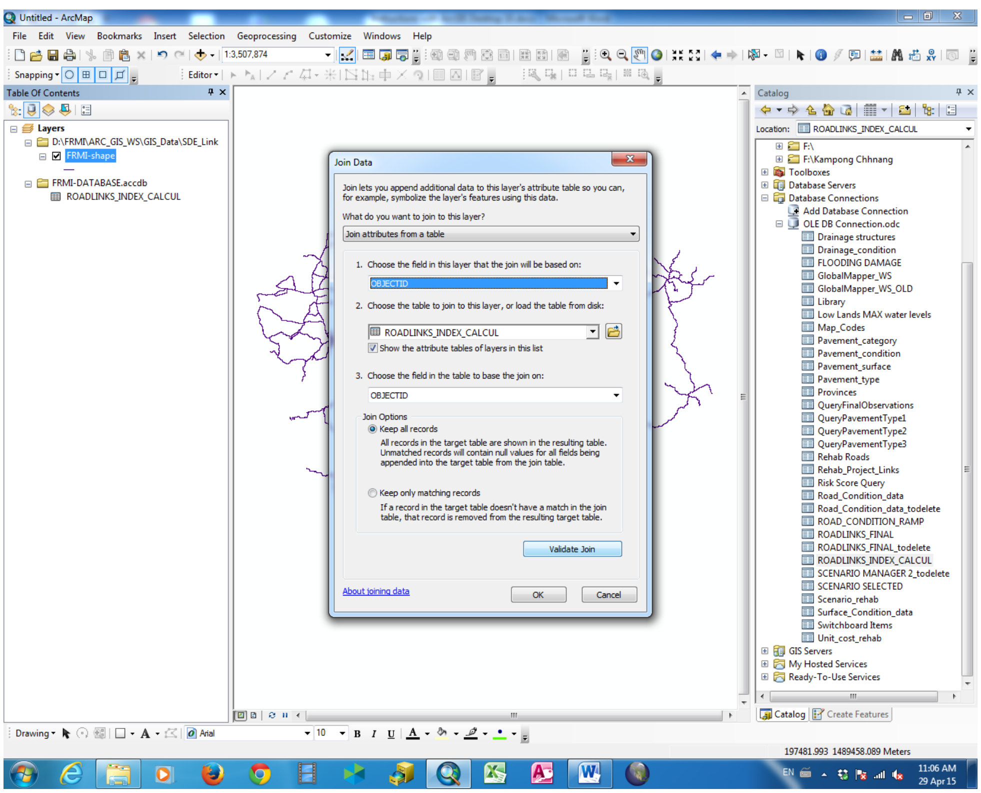


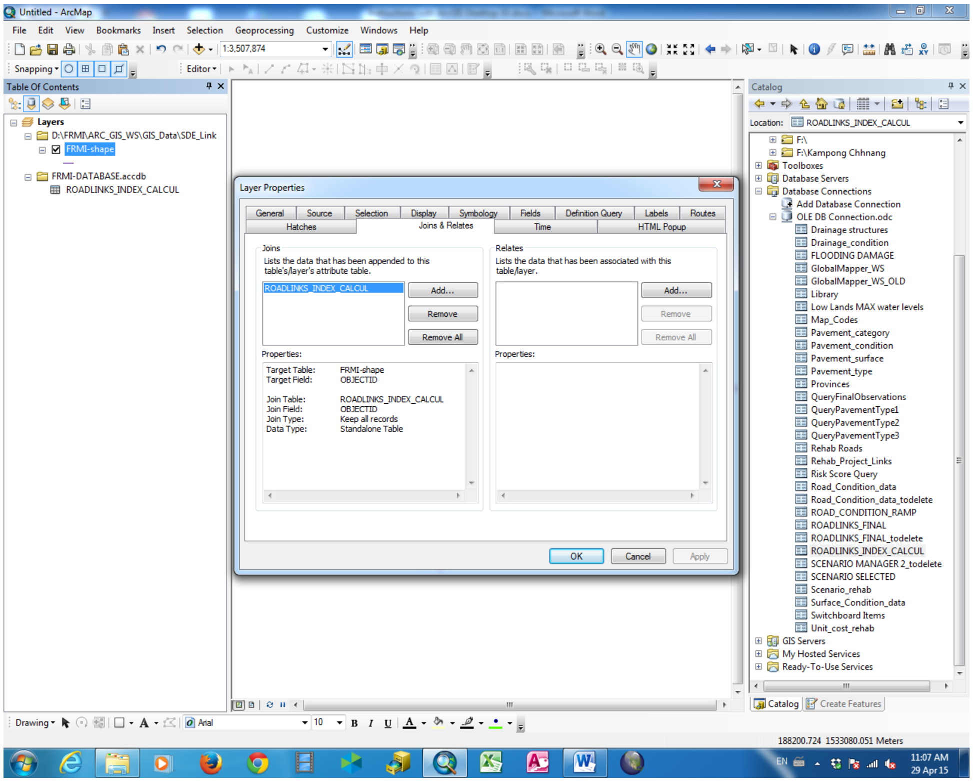
- **<u>Click and drag ROADLINKS_INDEX_CALCUL from ArcCatalog and drop into the Table of Contents (TOC)</u>**



- **Join FRMI-Shape with MS Access of ROADLINKS_INDEX_CALCUL**

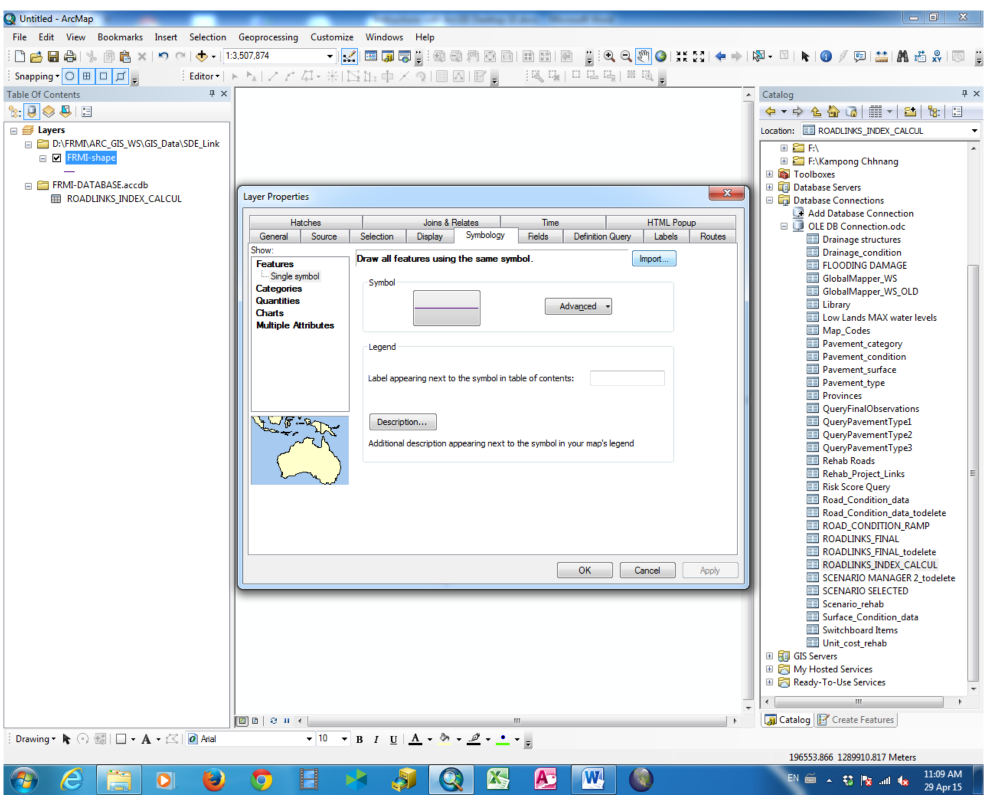


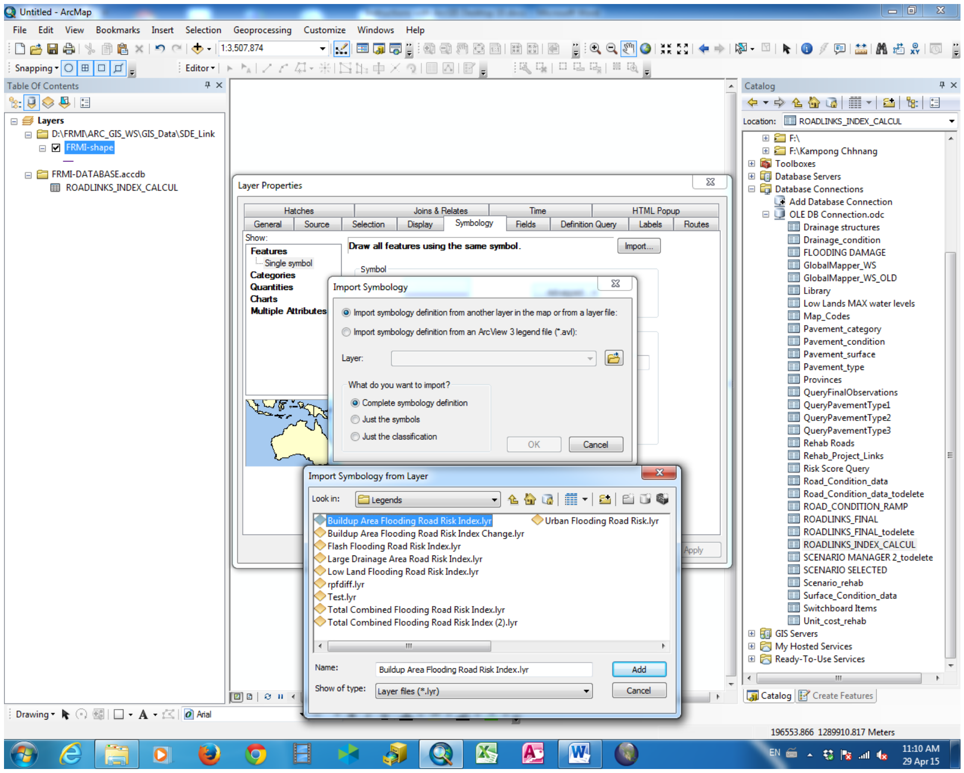


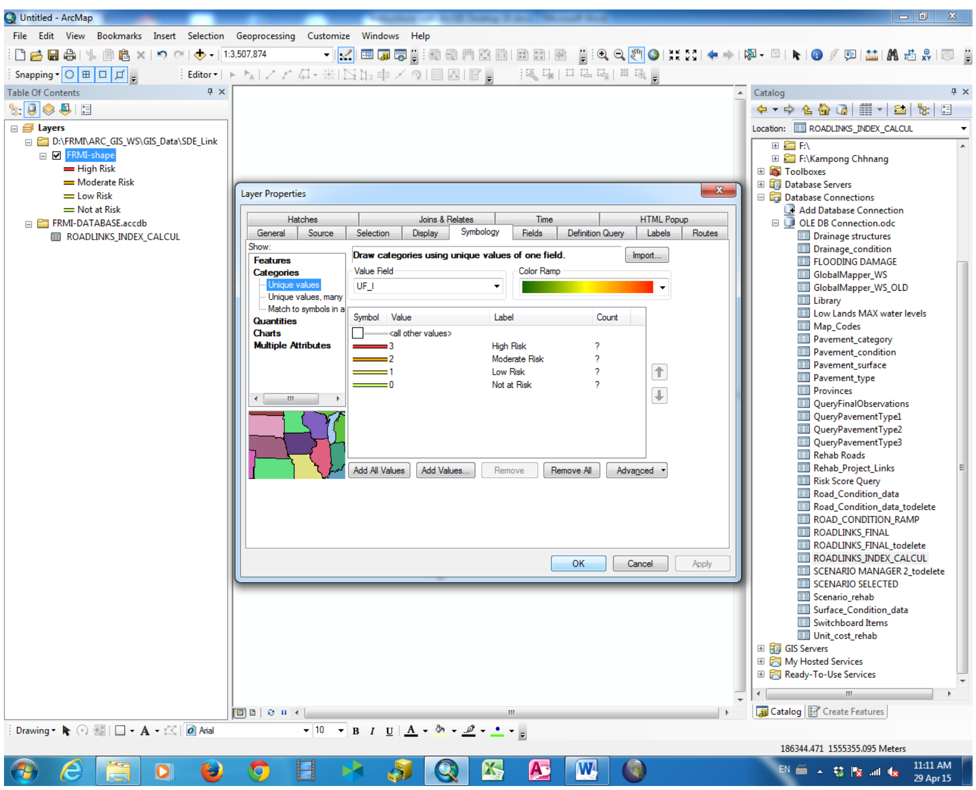


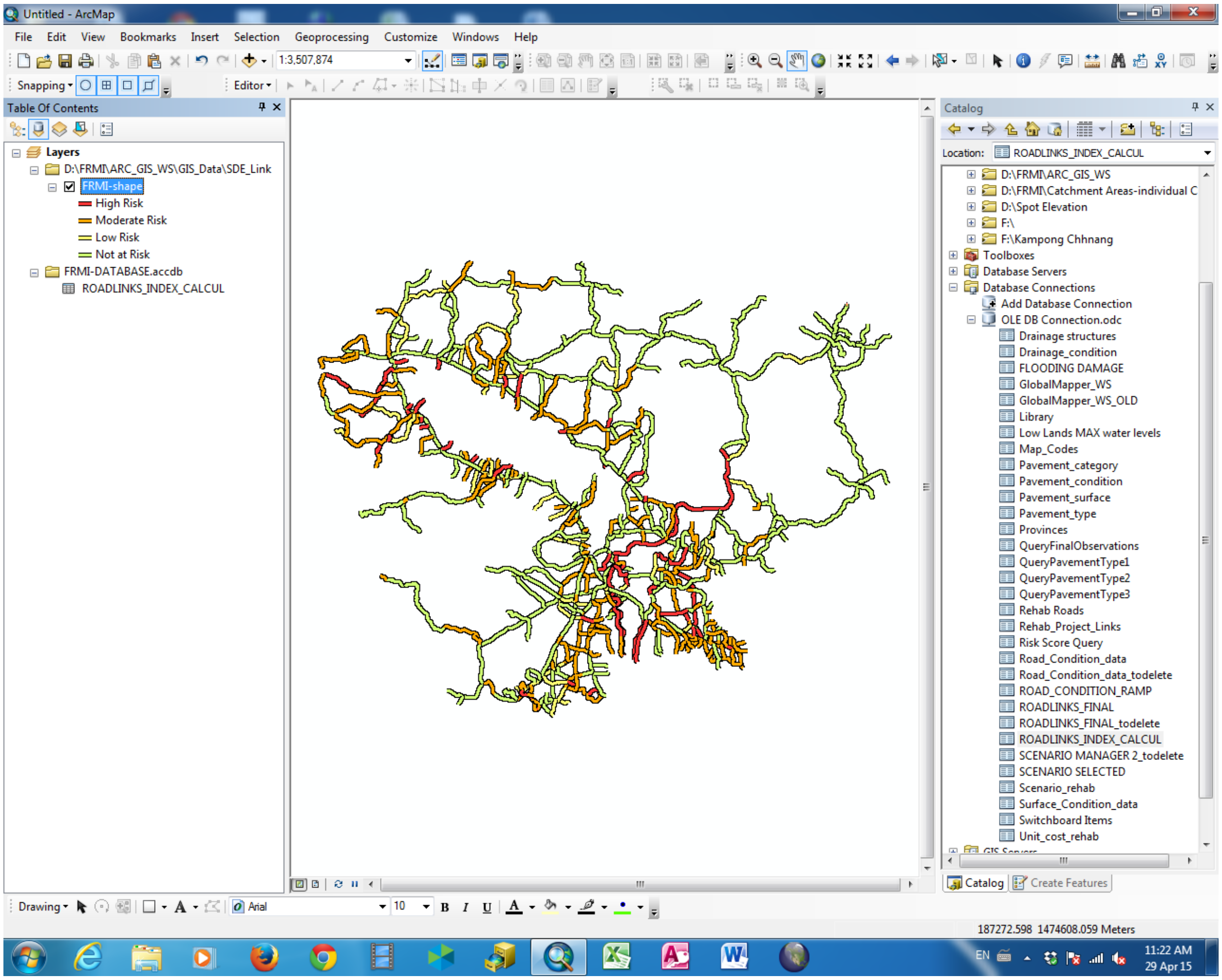
Join FRMI-Shape and Table of ROADLINKS_INDEX_CALCUL was successfully

- **Create a legend**









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1:3,507,874
Snapping
Editor
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FRMI-shape
High Risk
Moderate Risk
Low Risk
Not at Risk
FRMI-DATABASE.accdb
ROADLINKS_INDEX_CALCUL
Catalog
Location: ROADLINKS_INDEX_CALCUL
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D:\Spot Elevation
F:\
F:\Kampong Chhnang
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Database Servers
Database Connections
Add Database Connection
OLE DB Connection.odc
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Drainage_condition
FLOODING DAMAGE
GlobalMapper_WS
GlobalMapper_WS_OLD
Library
Low Lands MAX water levels
Map_Codes
Pavement_category
Pavement_condition
Pavement_surface
Pavement_type
Provinces
QueryFinalObservations
QueryPavementType1
QueryPavementType2
QueryPavementType3
Rehab Roads
Rehab_Project_Links
Risk Score Query
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Road_Condition_data_todelete
ROAD_CONDITION_RAMP
ROADLINKS_FINAL
ROADLINKS_FINAL_todelete
ROADLINKS_INDEX_CALCUL
SCENARIO MANAGER 2_todelete
SCENARIO SELECTED
Scenario_rehab
Surface_Condition_data
Switchboard Items
Unit_cost_rehab
Catalog
Create Features
Drawing
Arial
10
187272.598 1474608.059 Meters
EN
11:22 AM
29 Apr 15

Appendix 9

Instructions for updating FRMI Pavement condition data

Source: RAMS database

IRI data

Step 1

New pavement condition should be added in the ROAD_CONTION_RAMS table.

Structure of table (per LINK_ID)

ROAD_CONDITION_RAMP

Field Name	Data Type
LINK_ID	Text
TESTYEAR	Text
IRI	Number

Sample table

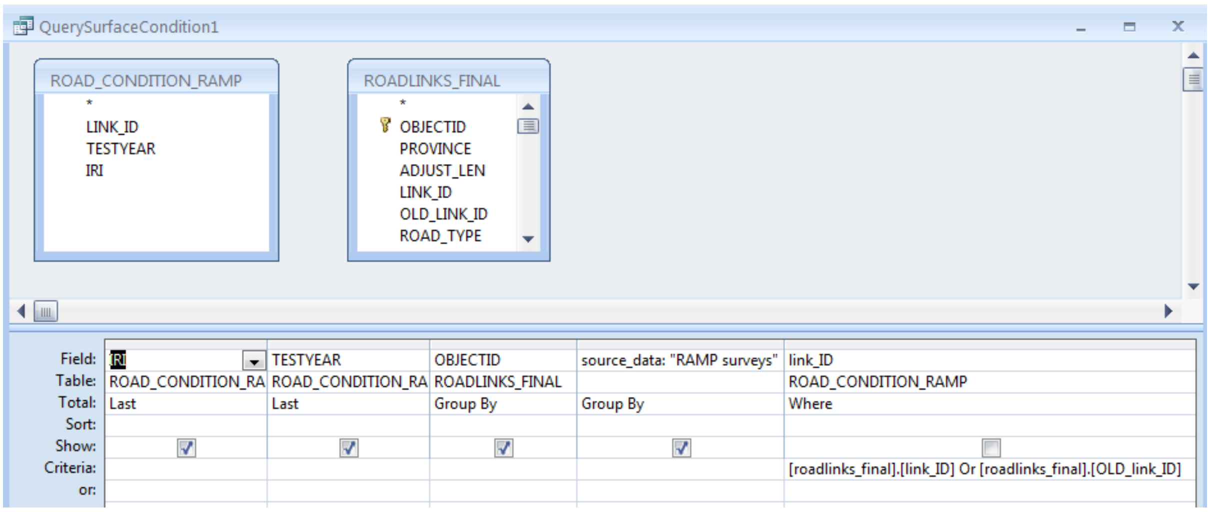
ROAD_CONDITION_RAMP

LINK_ID	TESTYEAR	IRI
001-000	2011	2.07200510204082
001-000	2014	2.62
001-005	2011	1.67011350540541
001-005	2014	2.83
001-008	2014	2.03
001-016	2011	1.75513753631285
001-016	2014	2.75656132532019
001-060	2011	2.38447065586592
001-060	2014	3.50674464612493
001-100	2011	3.63453371828572
001-100	2014	3.28818166079982
001-116	2011	4.00797405586592

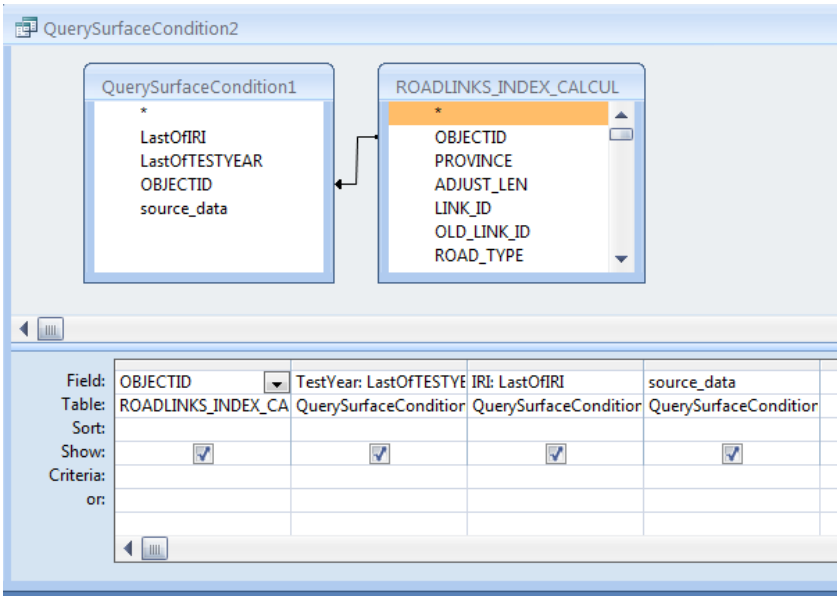
Record: 1 of 614 No Filter Search

Step 2

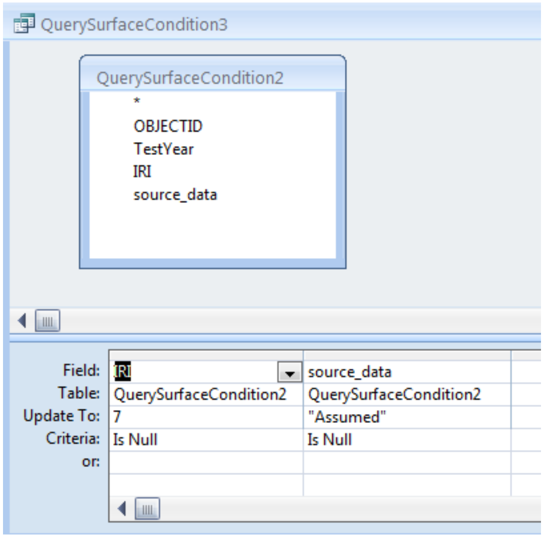
Identify source and filter for latest survey year



Create records for all OBJECTIDs and make table surface_condition_data



Fill up missing IRIs and sources using following query



Step 3

Final surface_condition_data table is as follows

Surface_Condition_data

OBJECTID	TestYear	IRI	Source_data
236	2011	12.5191872218487	RAMP surveys
237	2011	10.4181335791139	RAMP surveys
238		7	Assumed
239		7	Assumed
240	2011	11.7482823261803	RAMP surveys
241	2011	9.87245911382114	RAMP surveys
242	2011	10.8910963355705	RAMP surveys
243	2011	17.7304003265306	RAMP surveys
244		7	Assumed
245	2011	6.5873767	RAMP surveys
246	2011	5.9631321	RAMP surveys
247	2011	11.8717639585302	RAMP surveys
248	2011	7.31808403333333	RAMP surveys
249	2011	5.06498287980769	RAMP surveys
250		7	Assumed
251	2011	11.83831075	RAMP surveys
252	2011	9.12113285185185	RAMP surveys

Record: 1 of 553 No Filter Search

Pavement type data

Step 1

Assemble or update source table

The pavement surface is assembled in the Pavement_surface table as follows.

Structure of table

Pavement_surface

Field Name	Data Type
Link_ID	Text
From	Number
To	Number
Surf_Material	Text
Surf_Thick	Number

Sample table

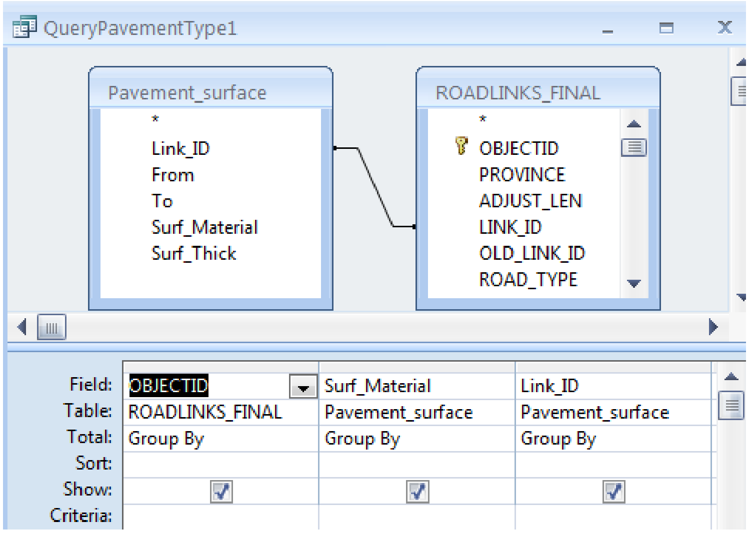
Pavement_surface

Link_ID	From	To	Surf_Materia	Surf_Thick
001-000	0	5092	AC	50
001-005	0	3535	AC	50
001-008	0	8098	AC	40
001-016	0	44427	AC	40
001-060	0	12354	AC	20
001-060	12354	36088	DBST	20
001-060	36088	37422	AC	50
001-060	37422	40438	DBST	20
001-100	0	794	DBST	20
001-100	794	1188	AC	50
001-100	1188	8875	DBST	20
001-100	8875	9396	AC	50
001-100	9396	15552	DBST	20
001-100	15552	17329	AC	50
001-116	0	2319	DBST	20

Record: 1 of 1604 No Filter Search

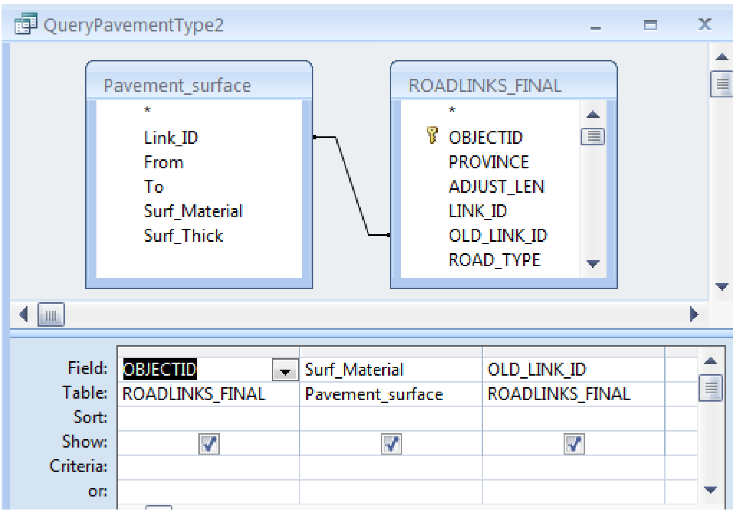
Step 2

Extracting LINK IDs



Step 3

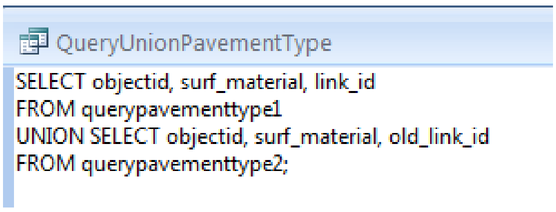
Extracting OLD_LINK_IDs



Step 4

Union of Link_ID and OLD_LINK_Ids

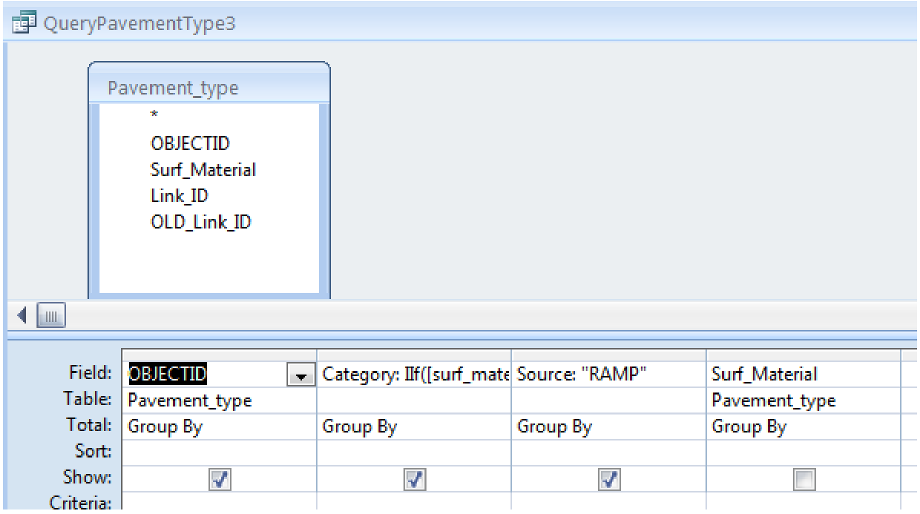
Run following Union query and make table Pavement_type


QueryUnionPavementType

```
SELECT objectid, surf_material, link_id
FROM querypavementtype1
UNION SELECT objectid, surf_material, old_link_id
FROM querypavementtype2;
```

Step 5

Building the pavement resilience type query

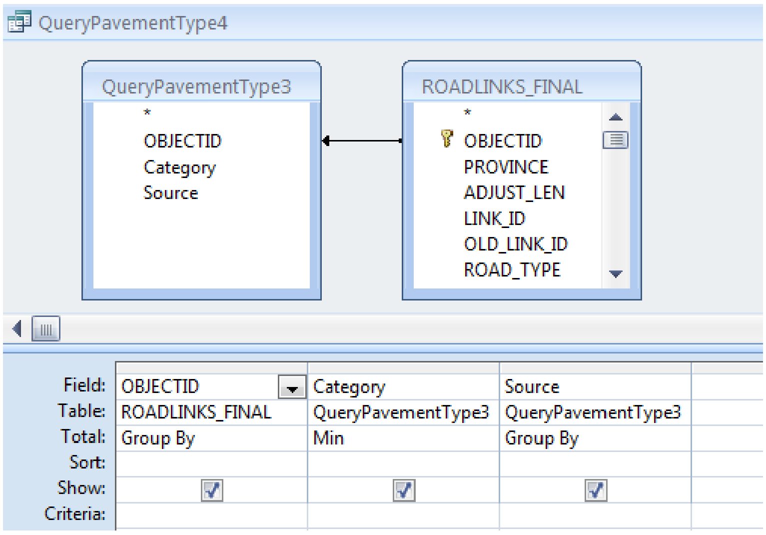


Where

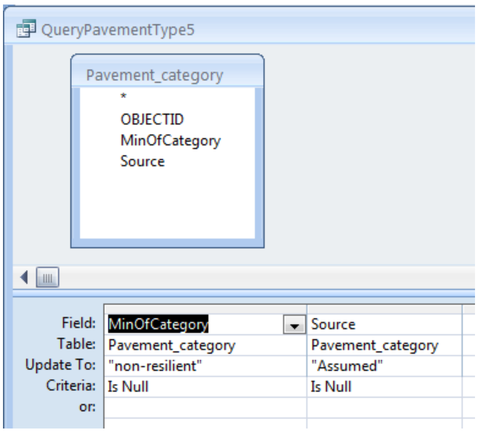
Category: IIf([surf_material]="AC" Or [surf_material]="concrete","resilient","non-resilient")

Step 6

Make table Pavement_category query



Fill up missing category types and sources using following query



Rehabilitation projects and overall pavement condition factor

Step 1

Source: Manually inputed table Rehab_roads with following structure:

Rehab Roads

Field Name	Data Type
project	Number
RoadNb	Text
Org	Text
Cost (Million USD)	Currency
length (Km)	Number
Cost Million USD/Km)	Currency
Section	Text
Year rehab start	Number
Year rehab end	Number
Status	Text
Pavement Type	Text
OBJECT IDS	Text

The following query associates the OBJECTIDs with projects using a manually built table called Rehab_Project_links.

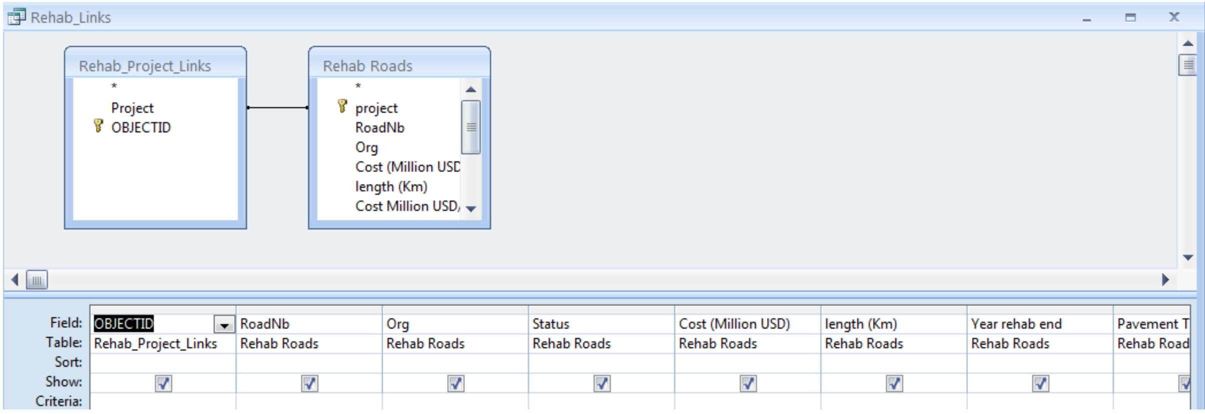
Step 2

Rehab_Project_links table structure is as follows:

Rehab_Project_Links

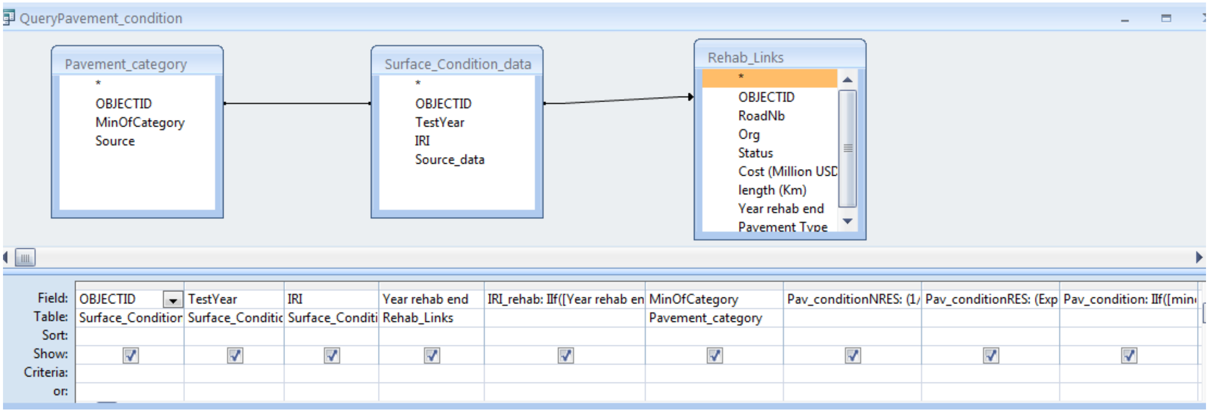
Field Name	Data Type
Project	Number
OBJECTID	Number

The query is:



Step 3

Query Pavement_condition and make table Pavement_condition



Where:

IRI_rehab: IIf([Year rehab end] Is Null Or [Year rehab end]<[testyear],[IRI],1)

Pav_conditionRES: (1/(1+Exp(3.5-[IRI_rehab])))

Pav_conditionNRES: (Exp(-3.5+[IRI_rehab]*1.3)/(1+Exp(-3.5+[IRI_rehab]*1.3)))

Pav_condition: IIf([minofcategory]="non-resilient",[pav_conditionNRES],[pav_conditionRES])

Main Output

Pav_condition in ROADLINKS_INDEX_CALCUL

Appendix 10

Instructions for updating FRMI Drainage structures condition data

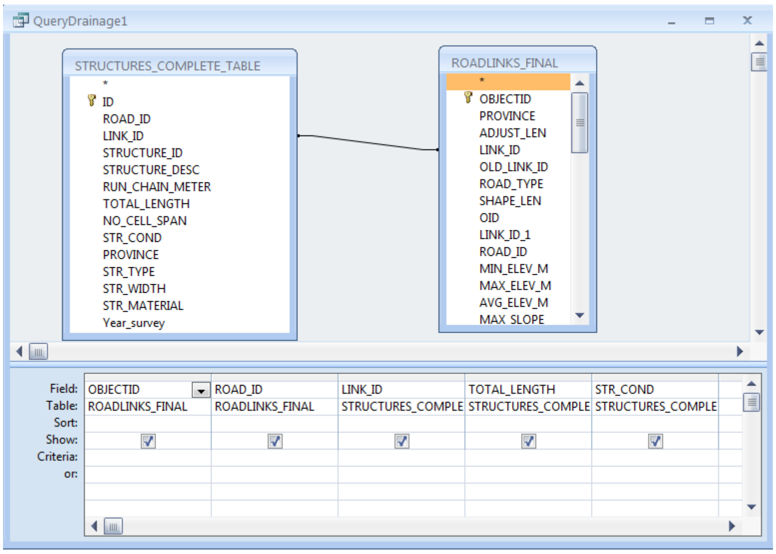
Source: RAMS database

Structure of RAMS drainage dataset

STRUCTURES_COMPLETE_TABLE

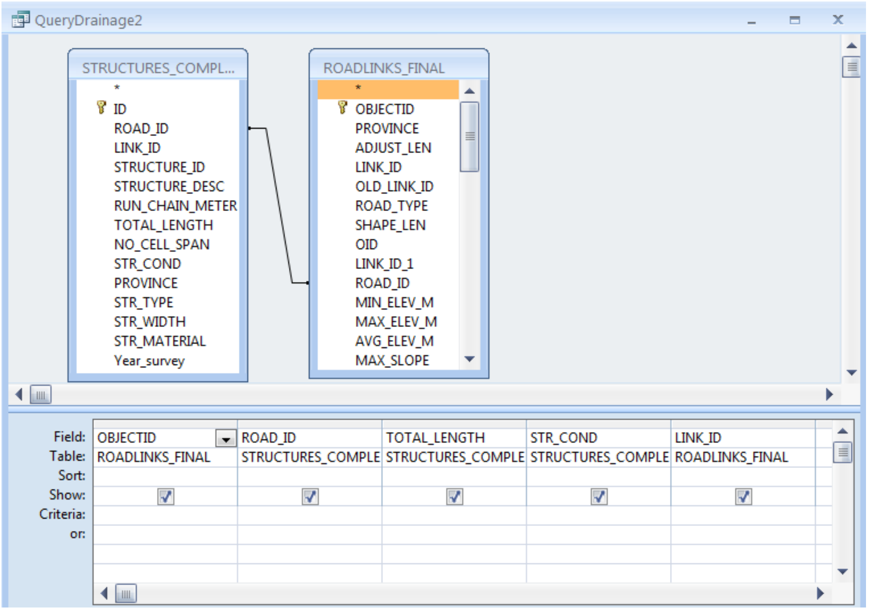
Field Name	Data Type	Description
ID	Text	From Ramp database
ROAD_ID	Text	
LINK_ID	Text	
STRUCTURE_ID	Text	ID of bridge or culbvert
STRUCTURE_DESC	Text	Name of bridge
RUN_CHAIN_METER	Number	in complete meters
TOTAL_LENGTH	Number	
NO_CELL_SPAN	Number	Number of cells
STR_COND	Text	Assessment 2003
PROVINCE	Text	Province
STR_TYPE	Text	Type of structure
STR_WIDTH	Number	Width of road
STR_MATERIAL	Text	Material of structure
Year_survey	Number	

Step 1



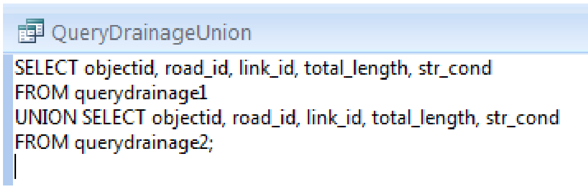
RoadsLinks_final is the reference CR-PRIP table

Step 2

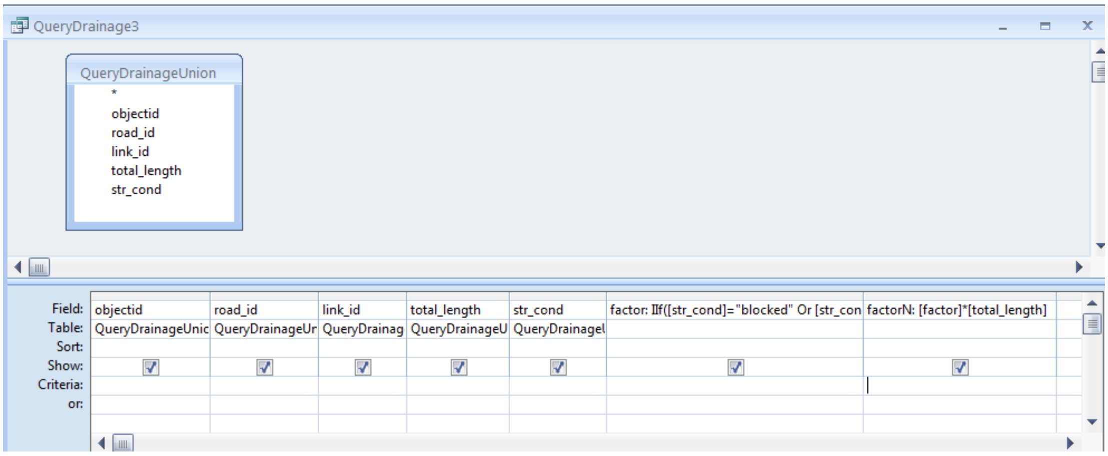


Step 3

Union of query1 and query2



Step 4

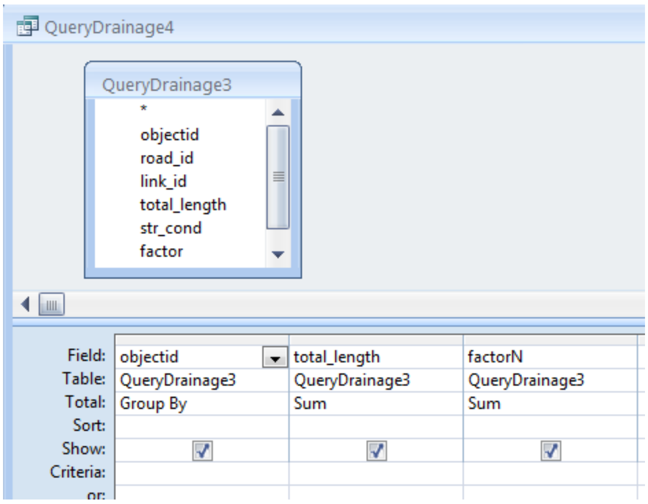


With

factor: IIf([str_cond]="blocked" Or [str_cond]="collapsed",1,IIf([str_cond]="broken",0.5,IIf([str_cond]="poor",0.25,0)))

Step 5

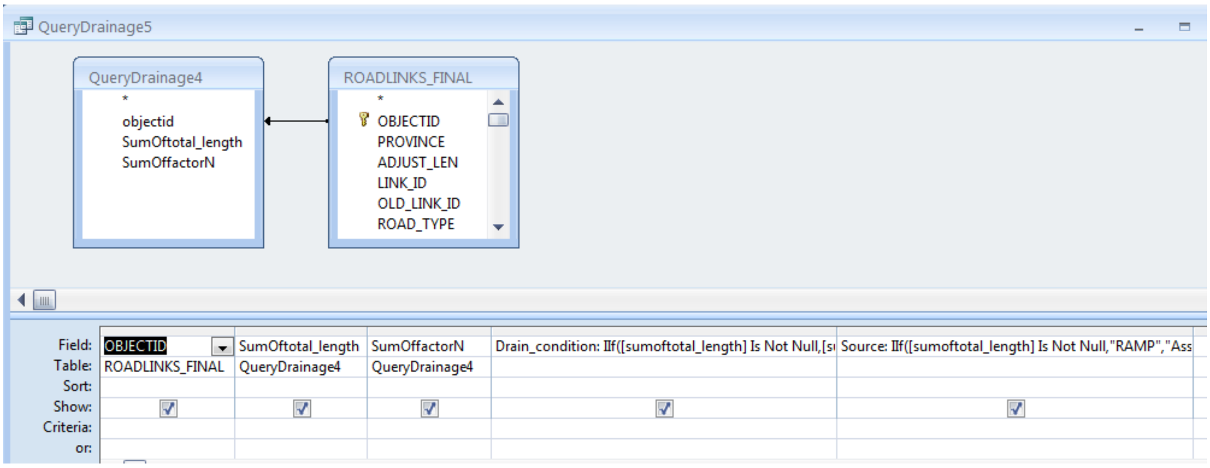
Calculation of sums for each OBJECTID



Step 6

Make table (and overwrite table “Drainage_condition”) with following query:

Calculation of drainage condition factor and source annotation



Where:

Drain_condition: IIf([sumoftotal_length] Is Not Null,[sumoffactorN]/[sumoftotal_length],0.5)

Source: IIf([sumoftotal_length] Is Not Null,"RAMS","Assumed")

Appendix 11

1 Instruction for inserting new road segments

Adding a new road segment into FRMI is a multiple step process. It requires the derivation of a GIS line feature and extraction of the required information from other datasets using GIS analysis.
The three major steps are

1. Create a new geographic line feature that represents the road centre line
2. Attach relevant road information - there are two possibilities for this step
   a. Inserting a new road segment, which exist in RAMS, but does not have any associated geographic information.
   b. Inserting a completely new section, which does not yet exist in RAMS
3. Derive the hydrological information required to calculate the road risk indicator values
4. Update the FRMI database.

It is assumed that a small number of new segments is inserted, which can be handled on a road by road basis.

1.1 Create a geographic line feature.

This task is preferably carried out in ARCGIS, as the geographic data base SDE_Link_FRMI can be manipulated directly. However, updating in GLOBAL MAPPER is also possible, but requires exporting and saving a new road link shape file.

Using ARCGIS

In ARCGIS you can add the new geographic line feature directly into the SDE_Link_FRMI shapefile

Open SDE_Link_FRMI file in ARCGIS. The SDE file is located in the FRMI folder and it is part of the PRIP - CR map files. If a geographic file of the target road is available, for example a topographic survey file or a GPS track, open these files together with the SDE_Link_FRMI file. All files have to be projected in WGS 84.

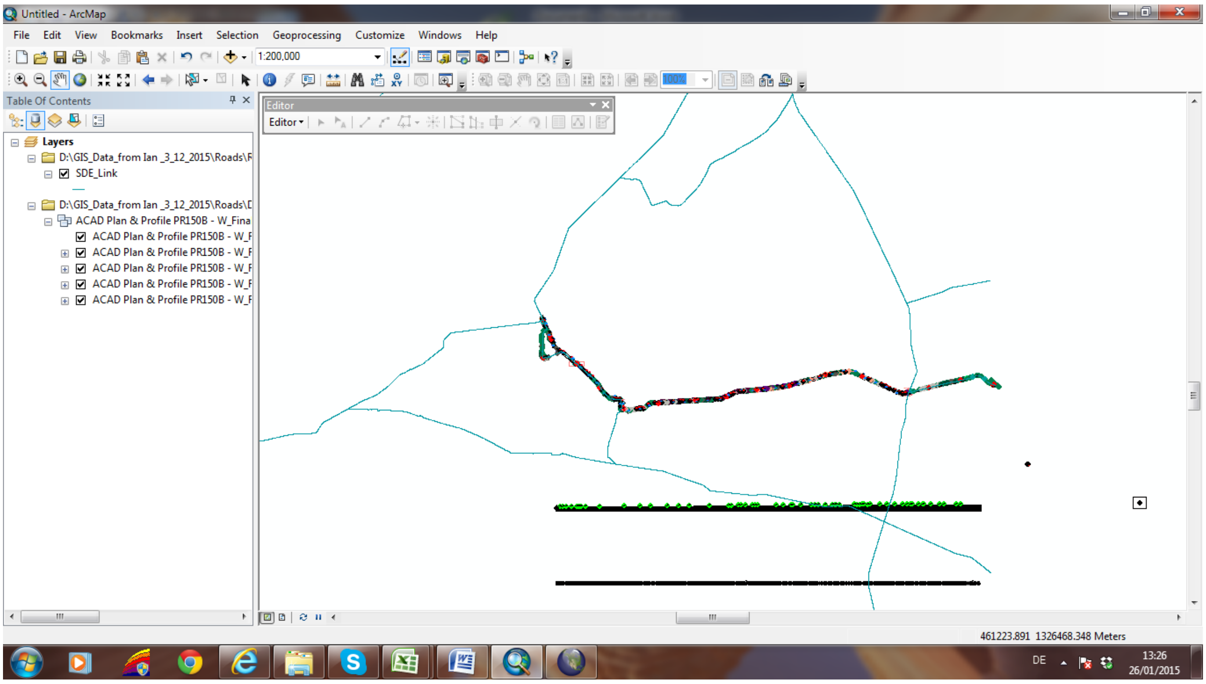


Figure 1: Loading graphic data into the SDE Link file

If the source file has a dedicated vector along the center line, this can be copied into the SDE_Link_FRMI and manual digitizing is not required. The vector is copied and pasted by using the right mouse click.

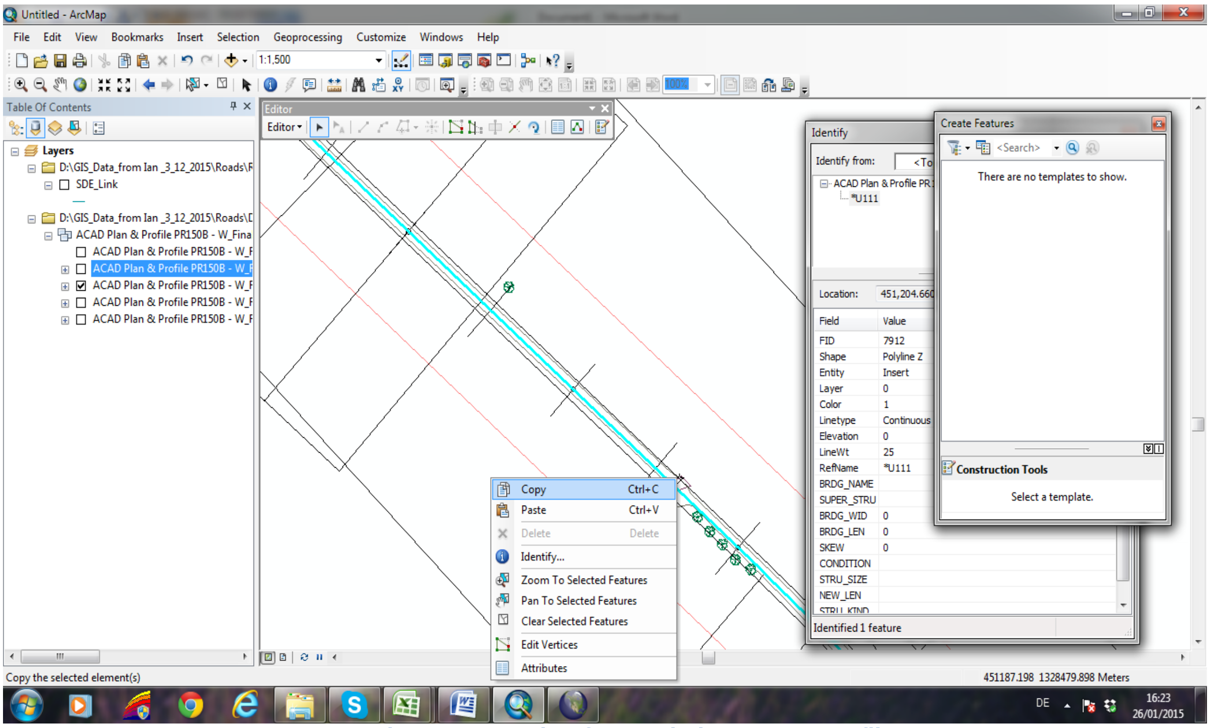


Figure 2: Copying from existing Auto CAD file

If manual editing is required, start the EDITOR Tool and chose SDE_Link_FRMI as feature to edit.

Edit the new link along the inserted vector and save your edits afterwards. Provide an unique Object ID, which has to be used to identify the new section in the FRMI database if mapping updates are processed.

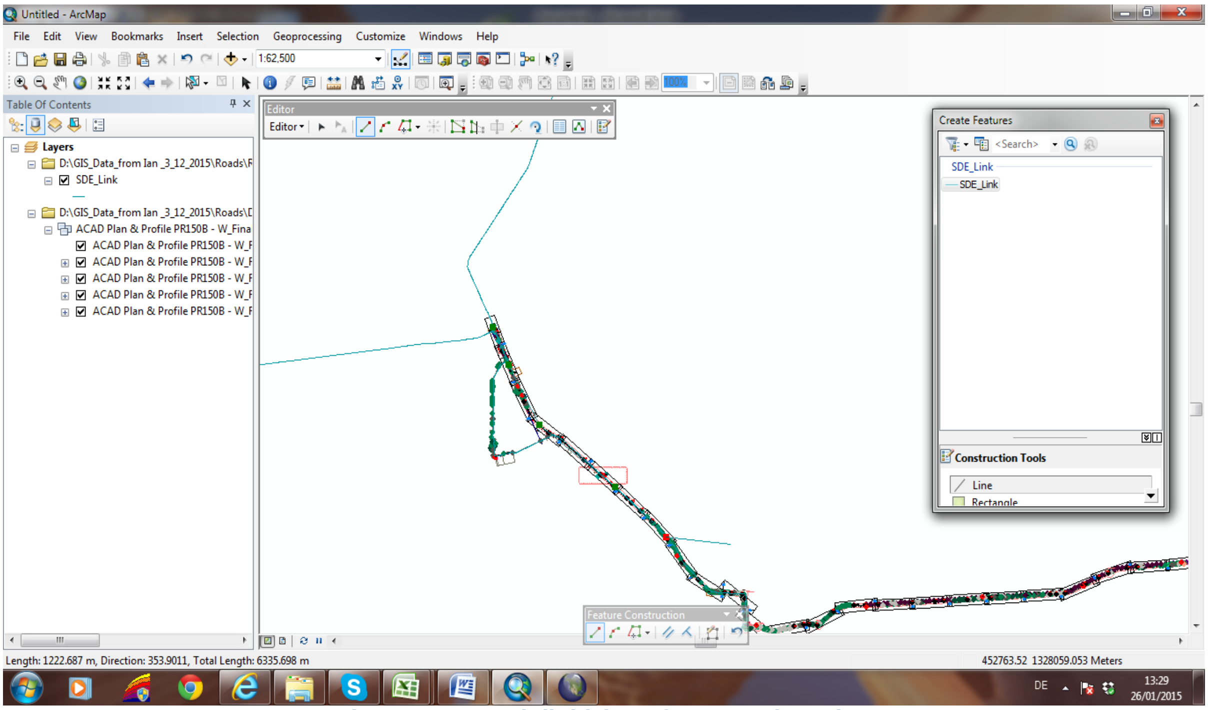


Figure 3: Manual digitizing of new road section

The final step is to add an Object ID that is required for identification in the FRMI database application and to attach the other information to the new feature.

Using Global Mapper

Open Global Mapper.

Load data set of target road. This data might originate from maps, topographic surveys, drone data or a geo-referenced Google image. Set the projection data to WGS 84, 48 North.

Open the SDE_Link_FRMI data set, which contains the geographic information used for producing the PRIP - CR Flood Vulnerability Maps, as shown on the screen shot. The SDE_Link_FRMI data set is stored in the same data folder as the FRMI interface application. The following image shows the topographic survey of a target road loaded into the Global Mapper work environment.

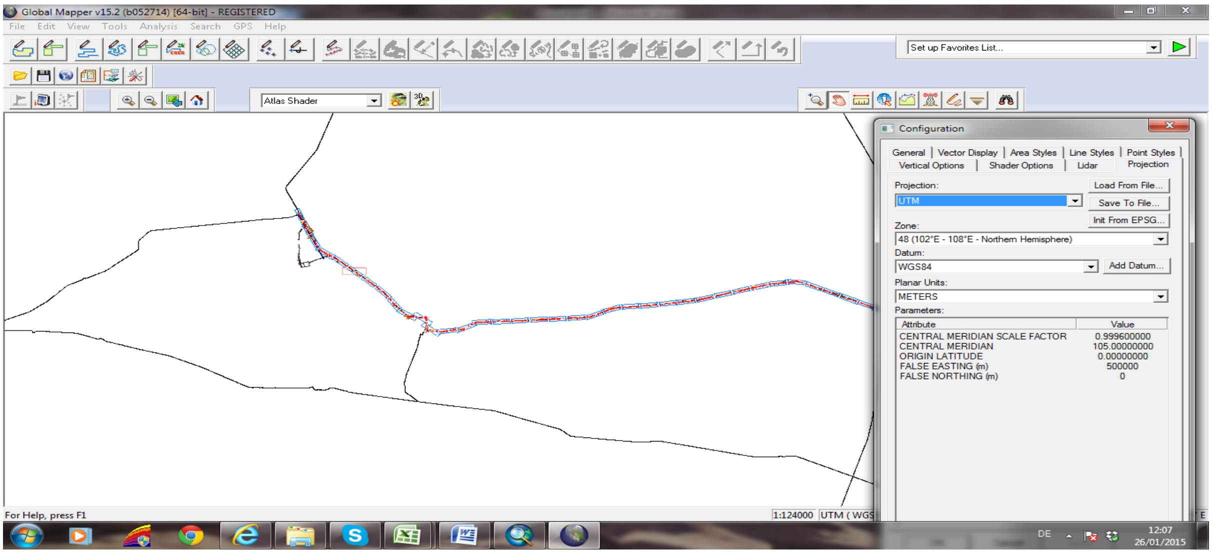


Figure 4: Loading Auto Cad file and SDE_Link_FRMI into Global Mapper

If the source data contains vector data, which already describes the target road properly (for example a center line vector of your topographic survey file, or a GPS track file) no manual digitizing is required. In this case the relevant vector can be simply copied onto the clipboard with a right click and then re-pasted into the SDE_Link_FRMI file.

If no dedicated road survey file is available, geo-referenced Internet data on the project road can be downloaded from the Internet.

Go to File/ Download Online Imagery/Topo /Terrain and connect to World Street Maps or World Imagery as shown below.

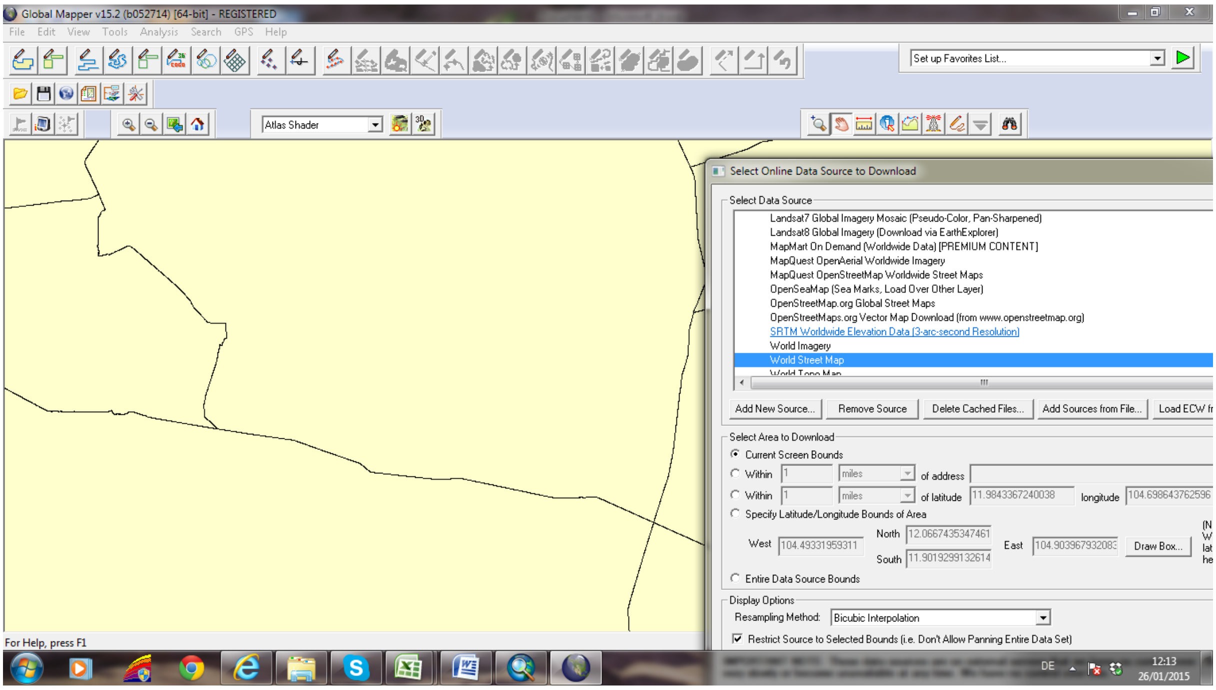


Figure 5: Loading road location information from the Internet

Download the image and arrange convenient view of the target road in the work window, as shown below.

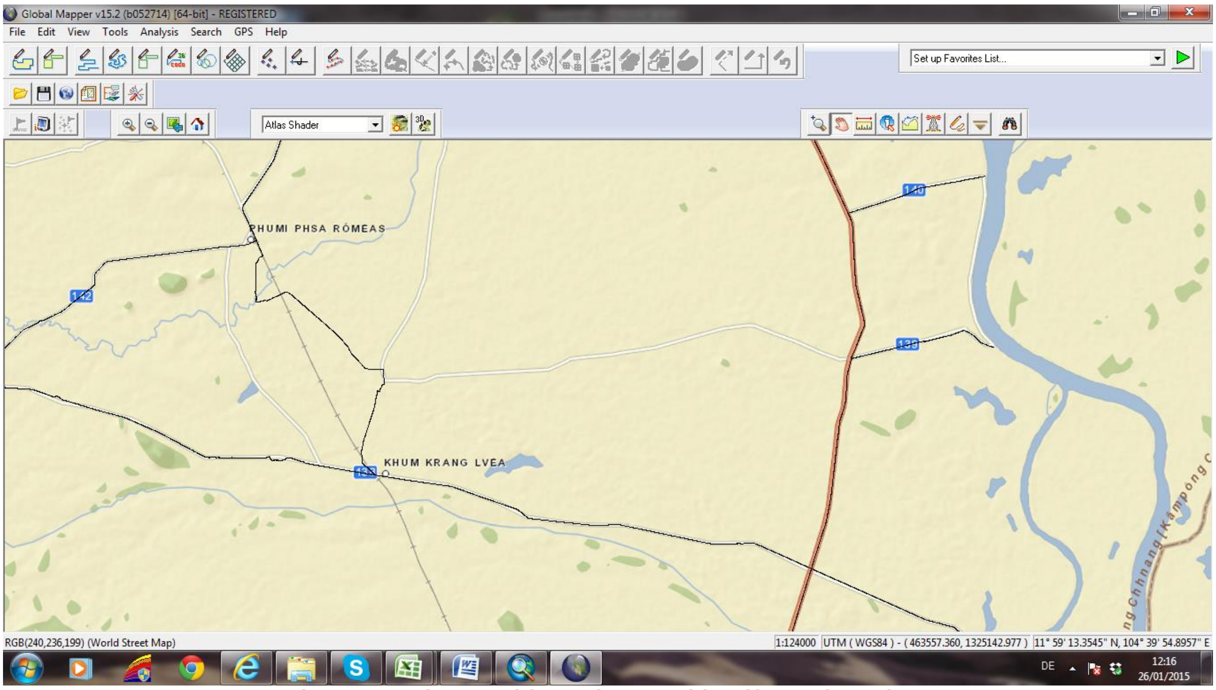


Figure 6: Using World Roadmap to identify road section

Now use the digitizer tool to create new road section manually.

Via the Tool menu or the Tool icon go to 'Digitizer'.

Click right to open the digitizing options and chose 'Create line Feature'. Here you have the option of TRACE or LINE (Vertex) mode. For the required degree of detail it is proposed to use the digitizer in Line mode.

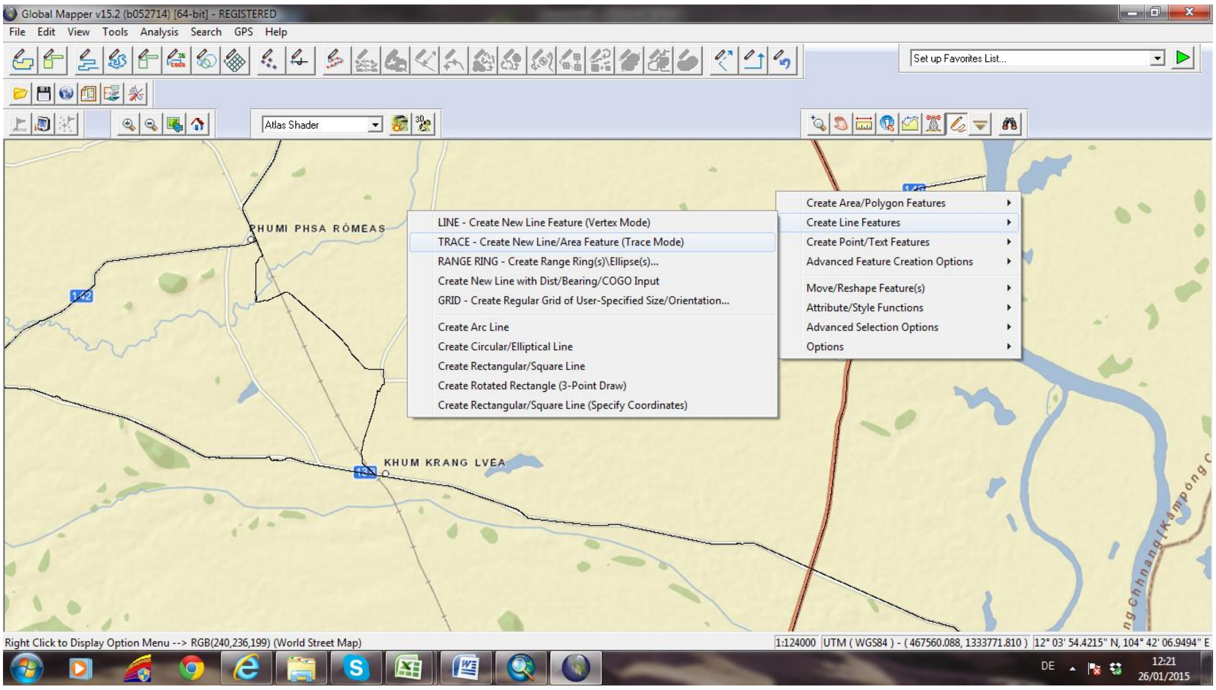


Figure 7: Preparation of manual digitizing of new road section

Digitize the target road. Start with a left click, set vertexes with left clicks and finish digitizing with a right click as shown below. Name the target road.

Adding an Object ID is required for identification in the FRMI database application.

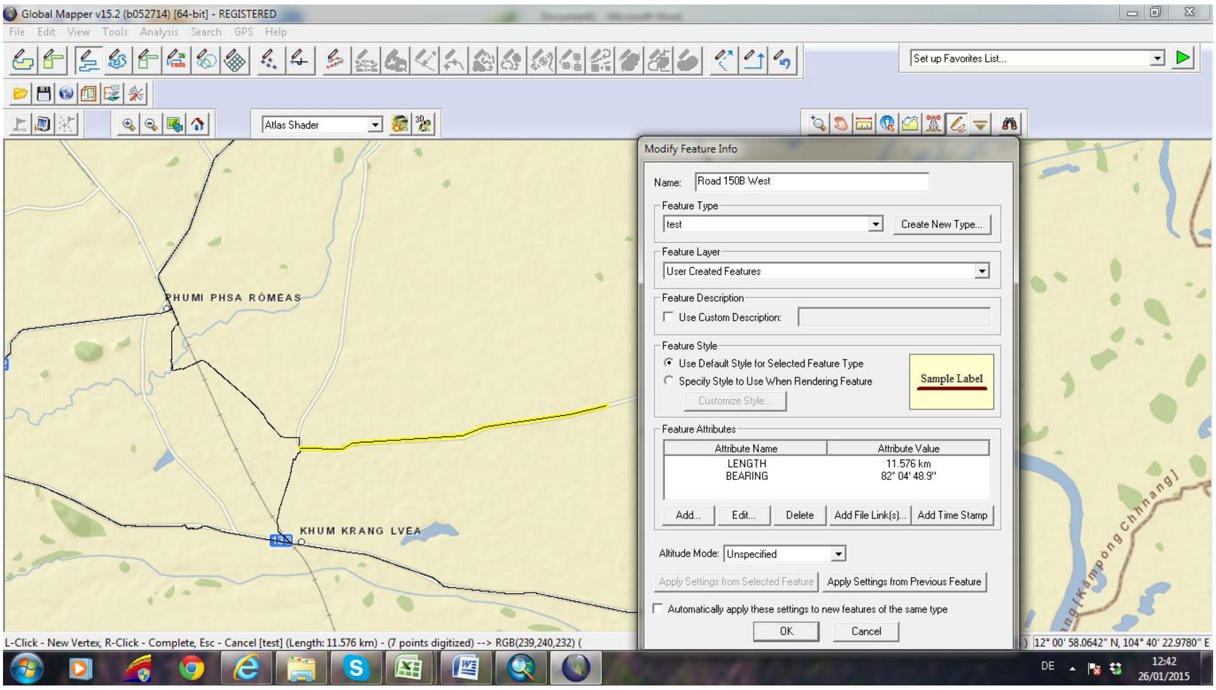


Figure 8: Digitizing process

Clicking on the target road will show 2 attributes to this new vector: Length and Bearing.

In the next step this vector will be added to the data layer permanently.

Use the Layer Control Center to close all background maps, but keep the User Created Features and the SDE_Link_FRMI layer switched on.

Go to File/Export/Vector/Lidar Format and chose Shapefile as Export format.

Chose Export Lines from the shapefile menu and save the dataset at an appropriate place. Click OK. This action will create 4 related files which from now on will be used as graphic input file for map production.

Close all data layers in Global Mapper.

Open all 4 SDE_LINK_FRMIS_ files. The new road section is now part of the SDE_Link_FRMI.

Adding an Object ID is required for identification in the FRMI database application.

1.2 Appending Basic Road Data to the non spatial table SD_Link_FRMI.xlsx.

Inserting a new road segment, which exist in RAMS, but does not have any associated geographic information.
Known attributes from the RAMS database such as Link ID and Road ID can be inserted into the SD_Link_FRMI.xlsx table.

Inserting a completely new section, which does not yet exist in RAMS
In this situation not only the Object ID used in the data base and the maps, but also all other data (Link ID, Road ID etc..) has to be 'invented' by the FRMI operator. Generally there are no limits to road names and classifications, but it seems appropriate to contact the RAMS data base manager in order to coordinate the input of new road section names in FRMI and RAMS.

One extra required parameter, the segment length, will be calculated in the next step

1.3 Derive the hydrological information required to calculate the road risk indicator values.

Analysis of basic road geometric parameters

For this analysis Global Mapper software is recommended.

Open Global Mapper and load the updated SDE_Link_FRMI shapefile into the work window.

Go to File/ Download Online Imagery/Topo /Terrain and connect to World wide SRTM. Elevation data.

Download an SRTM value which covers the extent of the relevant road section.

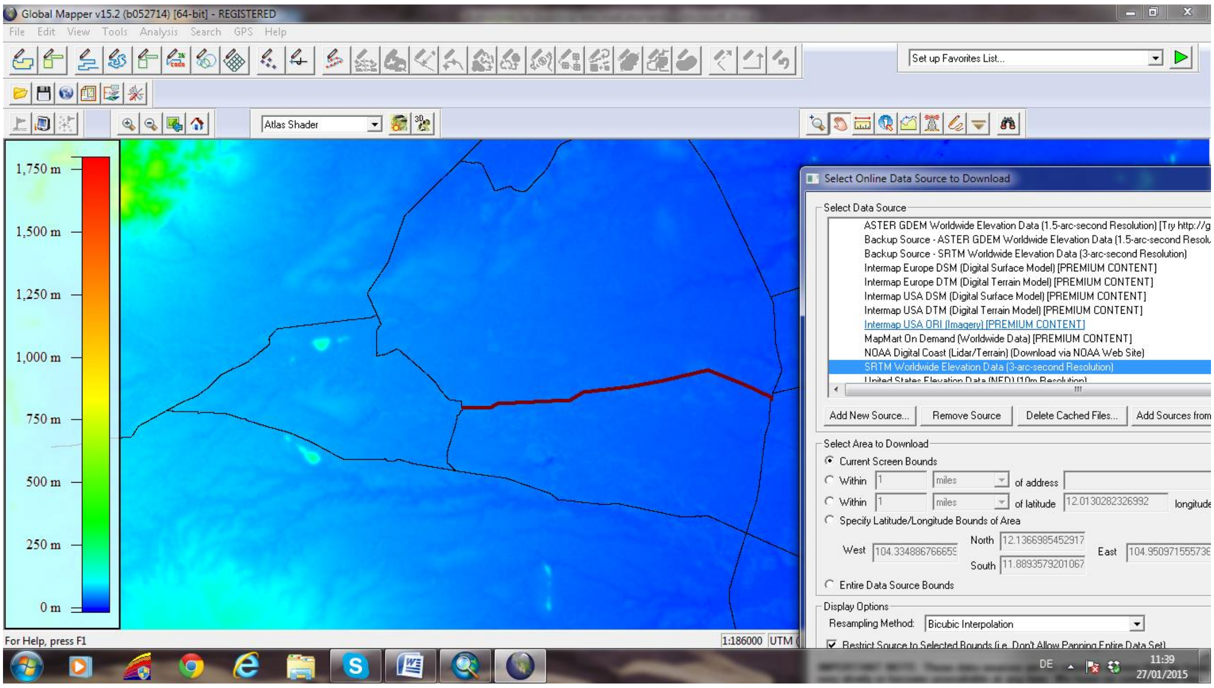


Figure 9: Analysis of road geometric parameters

Select the project road section with left click and then use the digitizer tool. Click on Analysis /Measurement /Calculate Elevation / Slope stats. The basic road geometry data is displayed on the screen.

Go to Analysis/Measurement and Measure/Display Feature Measurement. The results of the analysis can be exported as a CSW file and opened in Excel for further treatment. The relevant measurements gained in this analysis are:

- Length of road section
- Average Slope in %
- Average Elevation in m

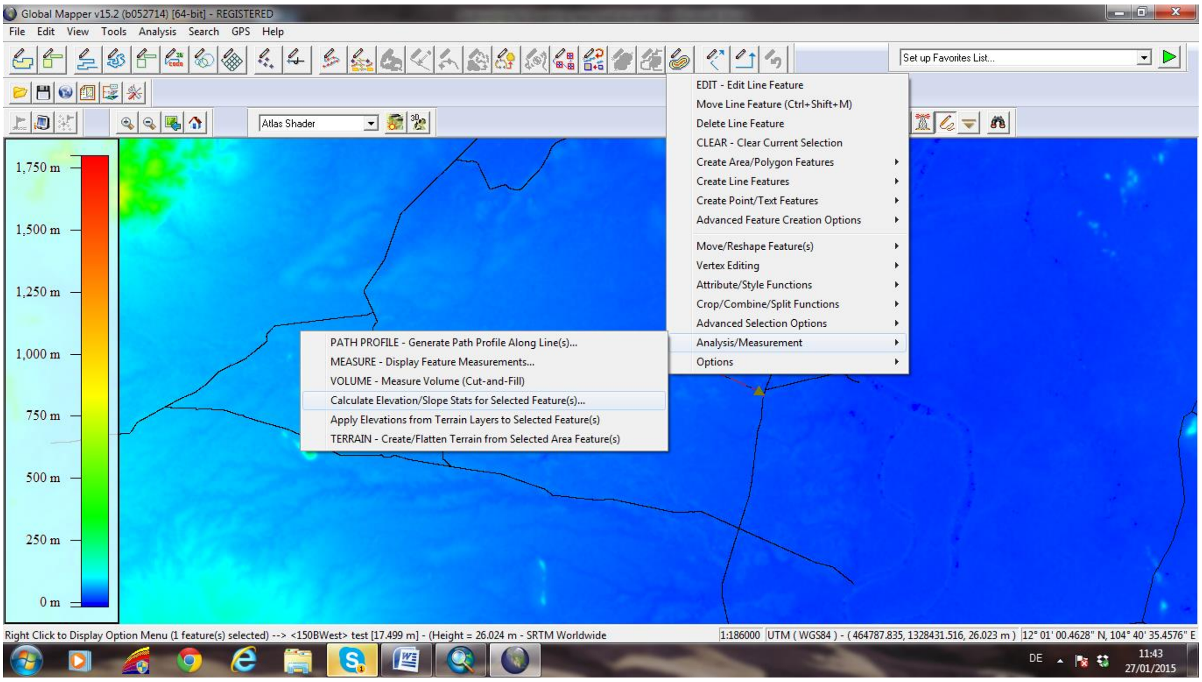


Figure 10: Menu for viewing geometric road parameters

STEP 3: Analysis of Drainage Area

The same work environment as can be used for analyzing the drainage area of the road section. However, as the target area is larger it is required to zoom out.

Close the SRTM data layer.

Reconnect to SRTM via File/ Download Online Imagery/Topo /Terrain and connect to World wide SRTM Elevation data.

Use the digitizer tool to activate the target road section. Go to Analysis/Generate Watershed

Choose appropriate cut off data for small drainage areas, e.g. 5 km2.

Tick the box: Create watershed areas **to selected line.**

Untick the box: Create watershed areas **from selected line.**

Chose a Resolution of 200 x 200 meters in order to reduce calculation time

Change to 'Watershed bounds' view and draw a box around probable drainage area.

Click OK and start analysis.

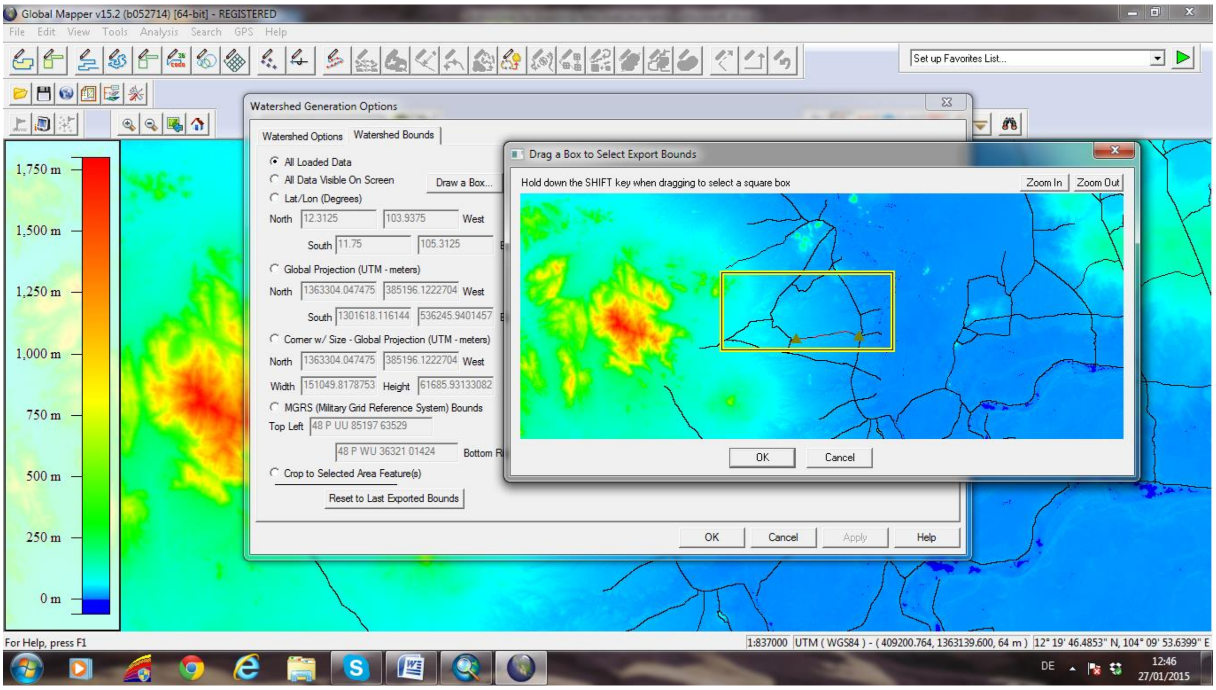


Figure 11: Selection of drainage area analysis area

View results of first analysis

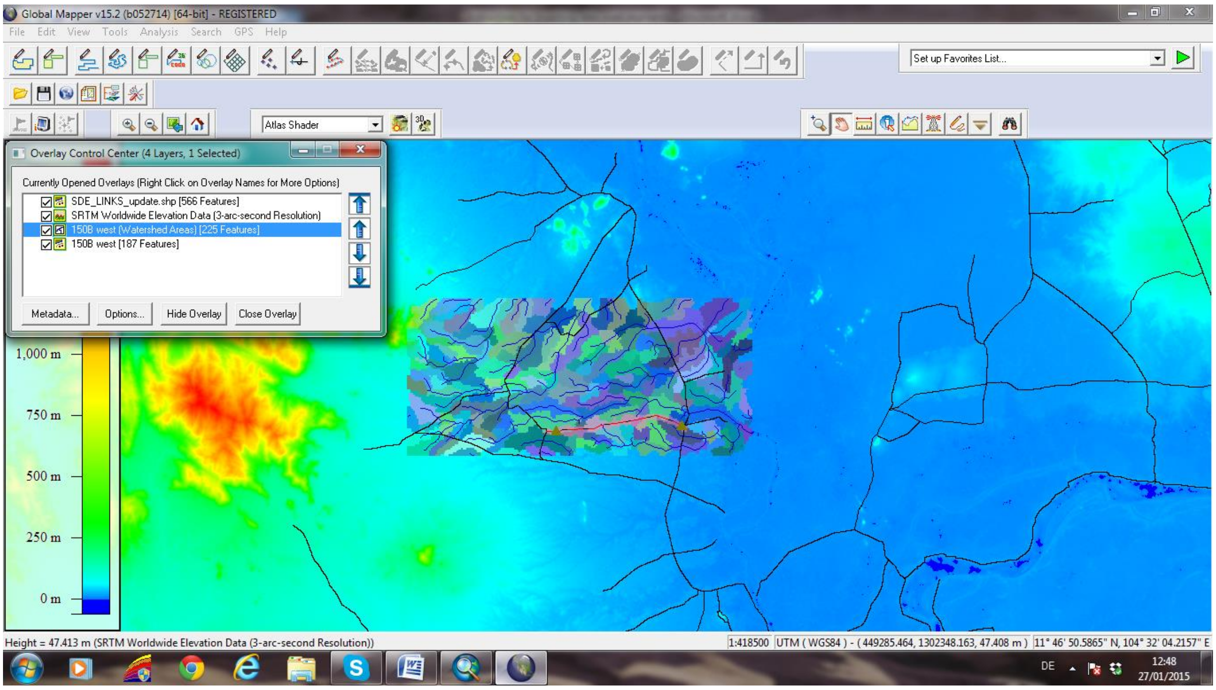


Figure 12: Result of drainage area analysis

Close [watershet AREAS] data layer and keep the single watershed data layer open.

Go to File/Export/Vector Lidar and chose Shapefile

Chose Export Areas and save the shapfile of the drainage area in an appropriate folder.

Switch off the watershed area data layer and remain with the SDE Link layer and the SRTM data layer.

Open the saved watershed file from your data folder. All four files (data file , projection file etc..) have to be opened to obtain the full information.

Use the Digitizer tool to select the water shed area.

Go to Analysis/ Measurement and chose Calculate Elevation / Slope Stats for selected features. The calculated watershed parameters are shown on the screen.

Go to Analysis/Measurement and select : Measure/Display Feature Measurement

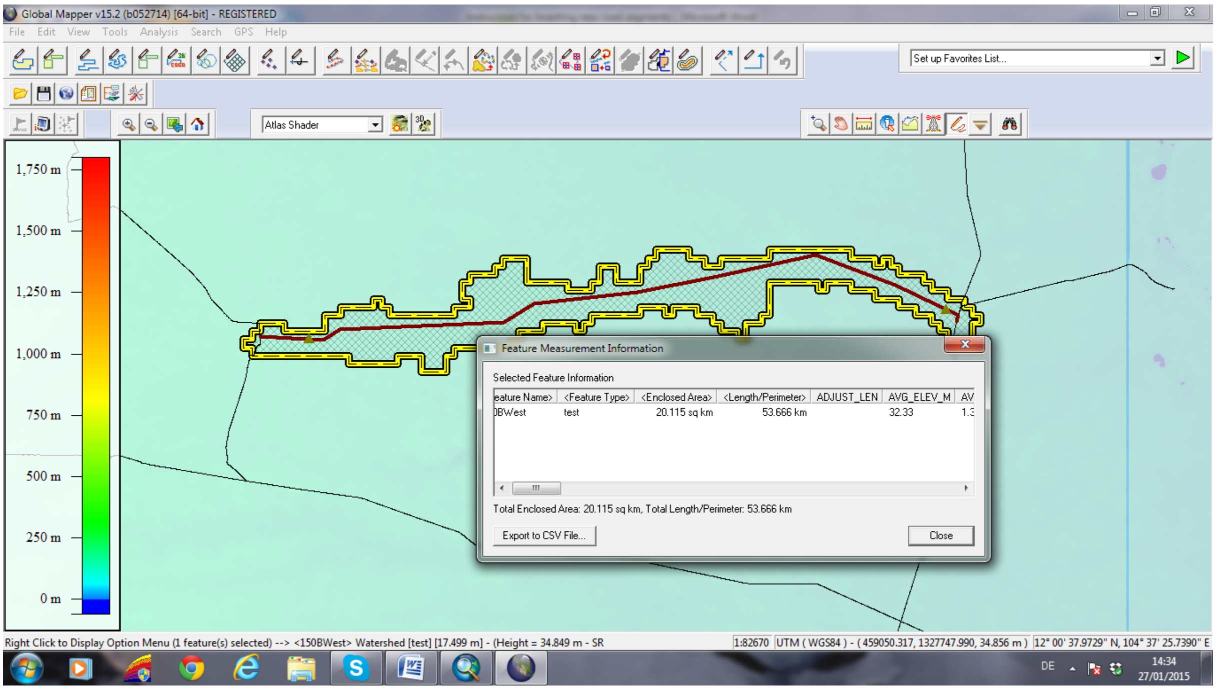


Figure 13: Export of drainage area analysis results

The result of the catchment analysis is shown in table format. It can be exported in CSW format.

The important parameters gained are:

- Drainage area surface area
- Average slope of the drainage area (not of the target road, but the drainage area)
- Perimeter of the drainage area

With this step all geometric road parameters have been measured.

- The Drainage Area / Road section length factor can be calculated, either manually or in Excel
- The Section Length /Perimeter factor can be calculated

In order to calculate the 4 Flood Risk Indicators a number of other parameters are required. A detailed methodology for extracting these parameter values is provided with the help files for updating the FRMI database. For a small road segment, the parameters values can be estimated from nearby or similar roads:

- Land use parameter from 0.2 to 1.0 as a medium value for the entire drainage area (0.2 forest, 0.5 agriculture, 1 urban)
- Urbanization ratio from 0 to 1.0 as a measure of percentage of built - up area next to the road corridor

- Rainfall data for the 1 day and 5 day extreme rainfall event and data for the 2055 climate change scenario design rainfall
- Bridge and road condition factors

Information on bridges and structures as well as on the road condition on the target road has to be gained from the RAMS data base or from field investigations. The cumulative bridge length divided by the road section length equals the Bridge Factor of the target road. This factor is required for the analysis of the Large Catchment area flooding index.

1.4 Updating the FRMI Database

The FRMI data base application uses one major table for road information that links with road condition tables.

If a single target road is to be updated open the RoadLinks_Final table in the Database application and enter data for the new road manually. A complete list of parameters is given in Appendix 4 of the FRMI manual. Road condition data tables should also be updated if condition data is available for the new segment (see Appendices 9 & 10 of FRMI manual).

It is recommended to use Object ID numbers down from 9999 in order to avoid doubling up on Object ID numbers. The Object ID number chosen during the graphic manipulations has to be used again in this table to link the data to the graphic output. If all parameters are inserted the program will automatically calculate the various flood indices and will map the result in the associated ARC View workspaces.

Appendix 12

Instructions for updating FRMI Land use data

Information on original Land use dataset

The landuse factor has values between 0 and 1.

In the 2015 version of FRMI, the values are derived from: The National Mapping Organizations (NMO) Global Land Cover (GLC) dataset which can be downloaded from the web for free. The data is a 1km (30 arc seconds) grid with 20 land cover classes. The NMO-GLC classification is based on the Land Use System developed by the United Nations Food and Agriculture Organization (http://www.fao.org/climatechange/54270/en/).

The 20 land cover classes of the NMO-GLC global image were reclassified into three values for input into FRMI using the following Table. These three values represent forest (runoff coefficient of 0.2), agriculture (runoff coefficient of 0.5) and areas with a runoff coefficient of 1 (water surfaces, exposed rocky surfaces and urban areas). The resultant reclassified image can be found on the D:/FRMI folder on the MPWT computer.

NMO_GLC Code	Name	FRMI Runoff Coefficient Value
1	Broadleaf Evergreen Forest	0.2
2	Broadleaf Deciduous Forest	0.2
3	Needleleaf Evergreen Forest	0.2
4	Needleleaf Deciduous Forest	0.2
5	Mixed Forest	0.2
6	Tree Open	0.5
7	Shrub	0.2
8	Herbaceous	0.5
9	Herbaceous with Sparse Tree / Shrub	0.5
10	Sparse Vegetation	0.5
11	Cropland	0.5
12	Paddy field	0.5
13	Cropland /Other Vegetation Mosaic	0.5
14	Mangrove	1
15	Wetland	1
16	Bare area, consolidated (gravel, rock)	1
17	Bare area, unconsolidated (sand)	0.5
18	Urban	1
19	Snow / Ice	
20	Water Bodies	1
255	no data	null

Procedure

The average runoff coefficient for the catchment of each road link was extracted using the **Zonal Statistics** tool (spatial analyst) in ARCGIS. The **ZONE** tool in QGIS can also be used. All of the catchments can be processed at once using a batch procedure.

Options to update in the future

Any landuse classification image can be used to generate a new runoff coefficient dataset. It is envisaged that when a new global land cover image is produced by NMO-GLC or another body, it will be imported into FRMI to ensure that up to date information is used in FRMI. Relationships between land cover classes and FRMI classes can be readily derived based on the previous Table. For further analysis these factors can be extended or fine-tuned to use a more sophisticated range of runoff coefficients.

Instructions for updating FRMI Rainfall data

Information on original rainfall dataset

Rainfall is input into FRMI as mm per day and an index is internally calculated

High quality data on rainfall intensity for short term events (6 hrs or less) are difficult to obtain for the entire country area of Cambodia. For the purposes of the FRMI it was assumed that change in rainfall intensity is reflected in 24 hour rainfall records and projections. It was also assumed that long duration high intensity events can be represented by a measure of 5 day extreme rainfall.

These data sets are raster data sets are stored in the FRMI dataset. In order to avoid rainfall having too large an effect due to the high totals in mm, the average extreme rainfall values for each road catchment were converted to an index with values that range between 1 and 2.2.

For both current and projected rainfall data in FRMI, 1 day and 5 day extreme rainfall datasets from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Conformal Cubic Atmospheric Model (CCAM) regional climate model were used. The CCAM model was run with inputs from 6 GCMs and data was extracted from all of the model runs. The 1 day extreme rainfall is defined as the maximum 24 hour total from 10 year model runs using the six GCMs. Similarly the 5 day extreme is the maximum 5 day total from six 10 year model runs (**Note 5 day extreme rainfall is expressed as mm per day in order to allow for the use of similar weighting values**). Current extreme rainfall values represents the maximum rainfall output for a period centred on 2005 and projected extreme rainfall values represent the maximum rainfall output for a period centred on 2055 using model runs with a RCP of 8.5. The current extreme values output by CCAM were used in preference to other available data sets in order to maintain consistency between current and projected rainfall data sets.

Procedure

The average value of each of the four rainfall intensity measures are extracted for the catchment of each road link using the **Zonal Statistics** tool (spatial analyst) in ARCGIS. The **ZONE** tool in QGIS can also be used. All of the catchments can be processed at once using a batch procedure. The extracted catchment averages are then converted to rainfall characteristics factors using a simple equation that is built into the FRMI database.

Options to update in the future

As results from new climate change modelling carried out for Cambodia become available they will need to be incorporated into FRMI. New modelling results that may become available include; the official release of MOE modelling, new statistical downscaling from MRC or new modelling carried out by MOWRAM.

Any new rainfall data may need to be converted into equivalent or similar values to those currently used in FRMI. The 1 day and 5 day extreme rainfall could be replaced by individual event values or statistically derived 1:100 year values. New average values for each road catchment can be extracted and a new equation to derive rainfall related indices would have to be incorporated into the FRMI interface.

Instructions for updating FRMI Build-up data

Information on original build-up dataset

Build-up ratio or Urban ratio has values between 0 (no built up areas) and 1 (entire length of the segment is built up).

The built up area index determines the risk of flooding due to hardening of surfaces directly left and right of the road corridor. The measure that is used is the percentage of road in the entire road segment that passes through areas classified as built up. The analysis has been carried out on the basis of a population map available at the MPWT that was developed as part of a former project funded by JICA. This vector layer consists of polygon features that represent built up areas.

Procedure

The **clip** tool is used to extract the parts of the line features of the road dataset that passed through a built up polygon. The length of these new features is derived using **Calculate Geometry tool** in ArcGIS or **Export/Add Geometry Column** in QGIS and summed by road segment to calculate a new value of urban length. The percentage is then calculated and converted into values between 0 and 1.

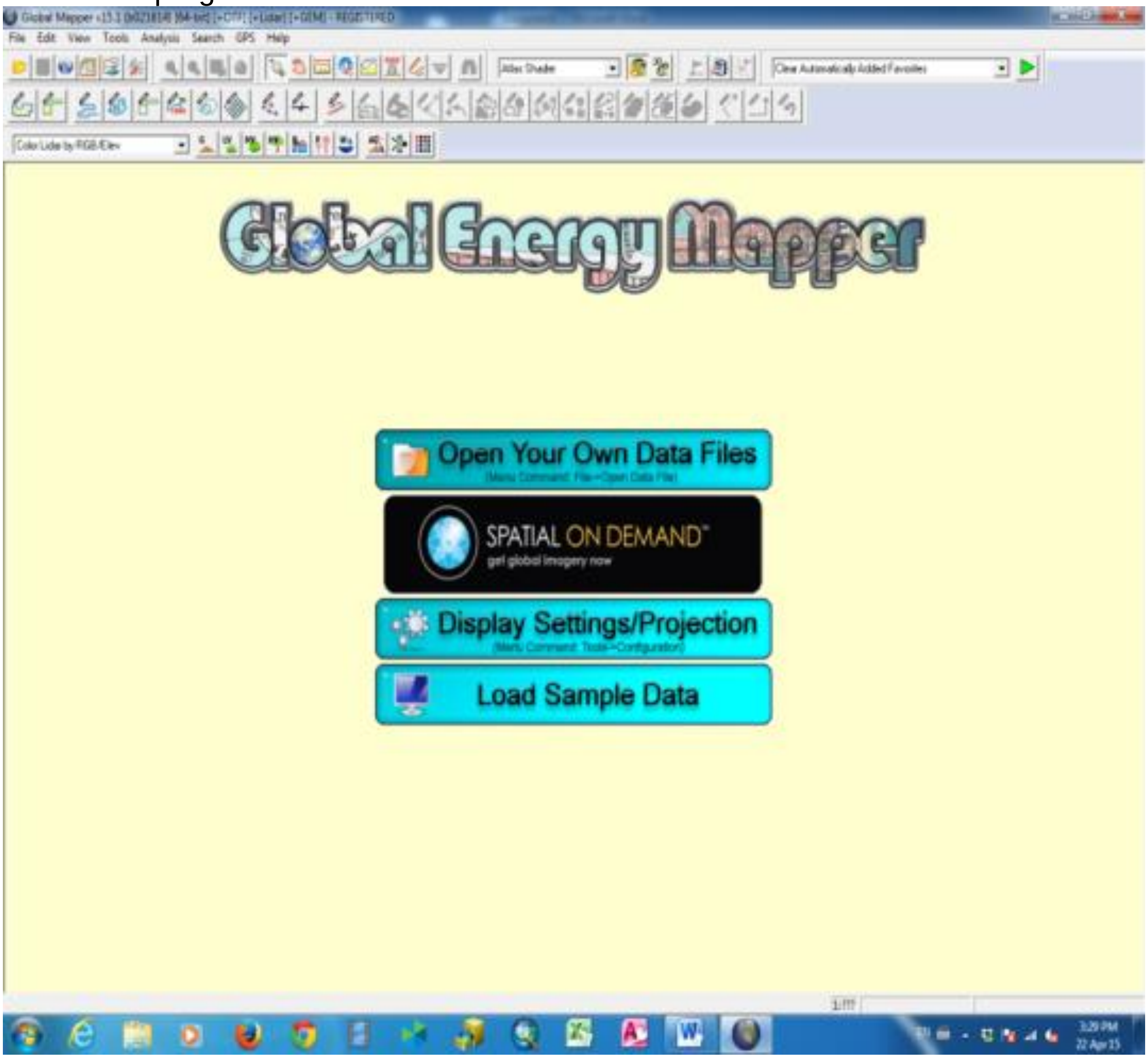
Options to update in the future

The current JICA population shape file was digitised in 2002 from a variety of sources; Landsat satellite data (1995 & 2000) and SPOT (1995-1996 & 1998-2000), and aerial photographs (1992-1995). Therefor the data is 15 to 20 years old and it would be advisable to update the information using new digitised data based on recent satellite imagery if it can be obtained from the relevant Government Ministry in the future.

Appendix 13

Introduction to Global Mapper

I/. Start the program

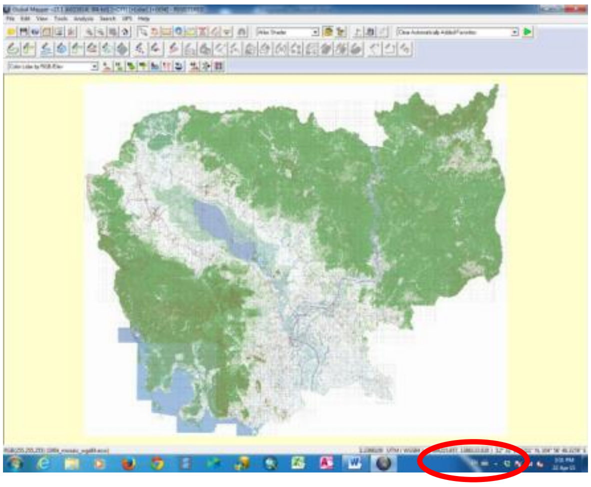


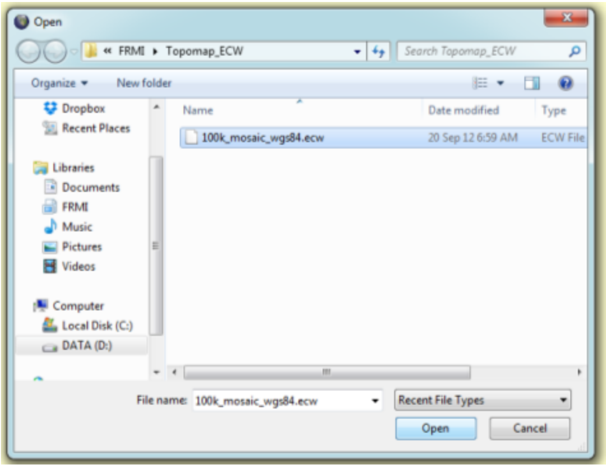
II/. Adding data

To add any shapefile data, you have to:

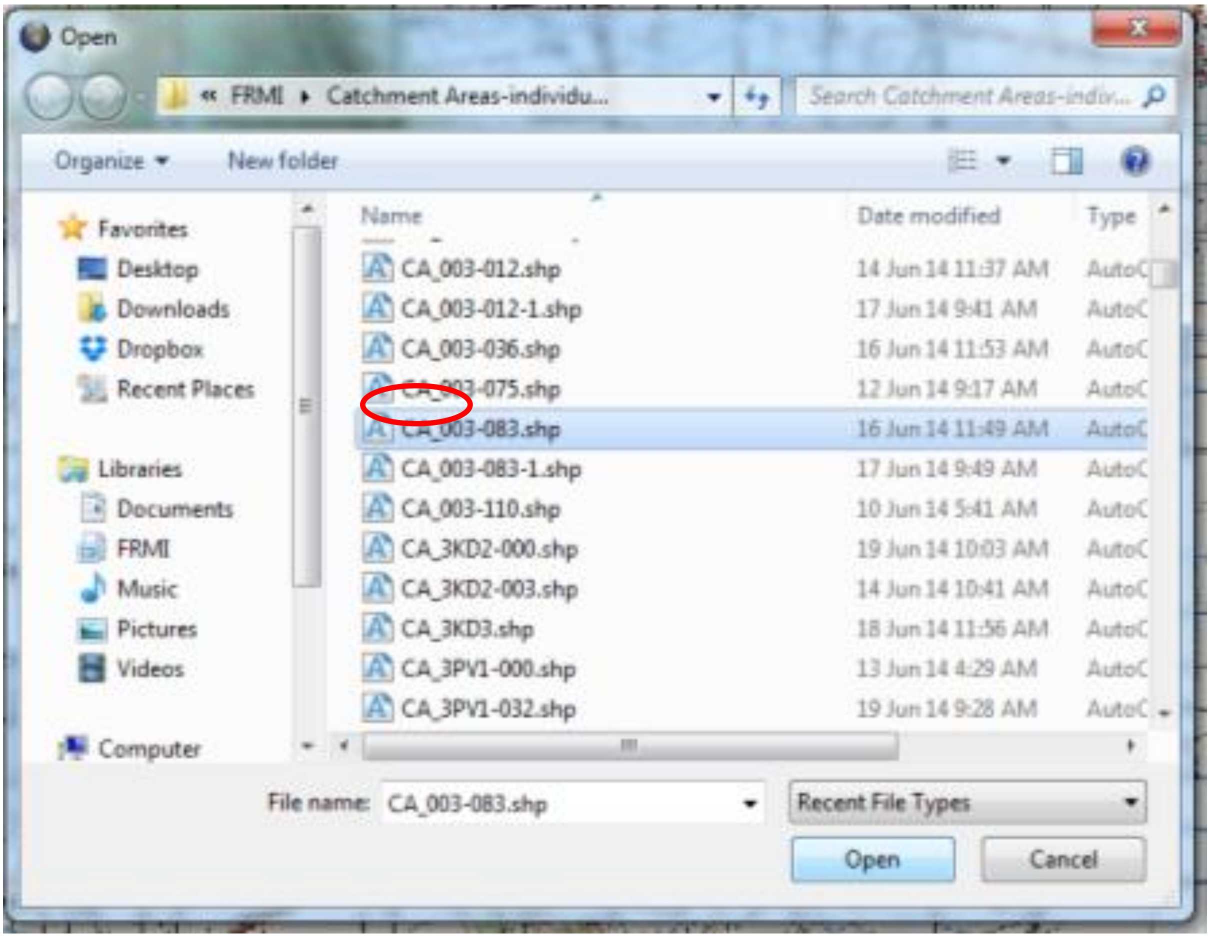
1. Click on File Menu
2. Click on Open Data File(s)…
3. Navigate to the Folder where the data is stored.

Load a **Topographic map** named 100k_mosaic_wgs84.ecw, located in Local (D):>FRMI>Topomap_ECW and then click Open, the Map will be displayed as the right image.

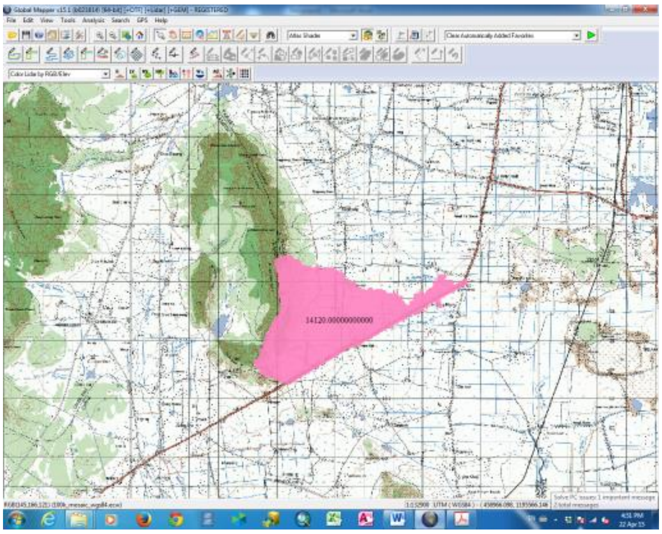




Load a **Road Catchment Area** layer in shapefile data. By navigating to <u>Local (D):>FRMI> Catchment Areas-individual CAs</u>, then click on any shapefile, here we choose <u>CA_003_038.shp</u> as example, after that click Open.



The map will come out as below. If you cannot see the Catchment Area, you can right click on that layer (CA_003_038.shp), click on ZOOM_TO – Zoom to selected layer (s), when you click on Open Control Center Icon.

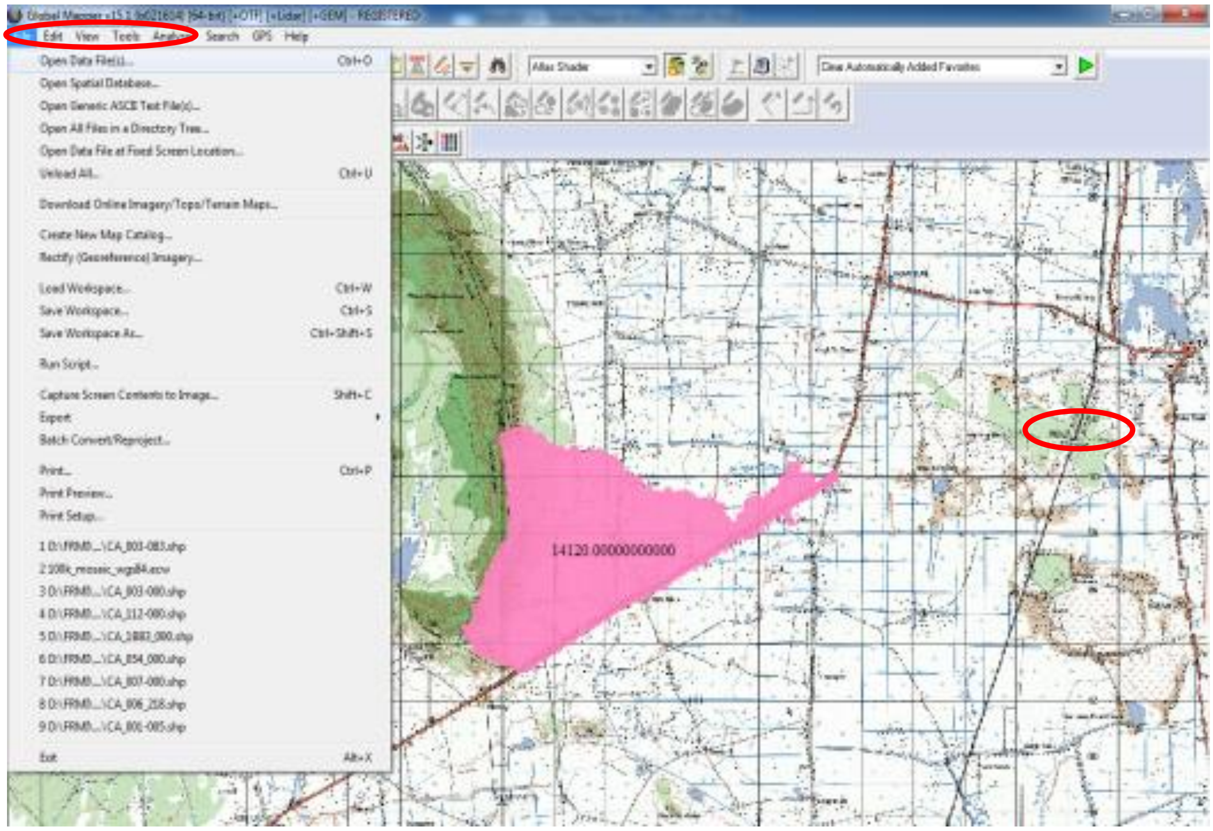


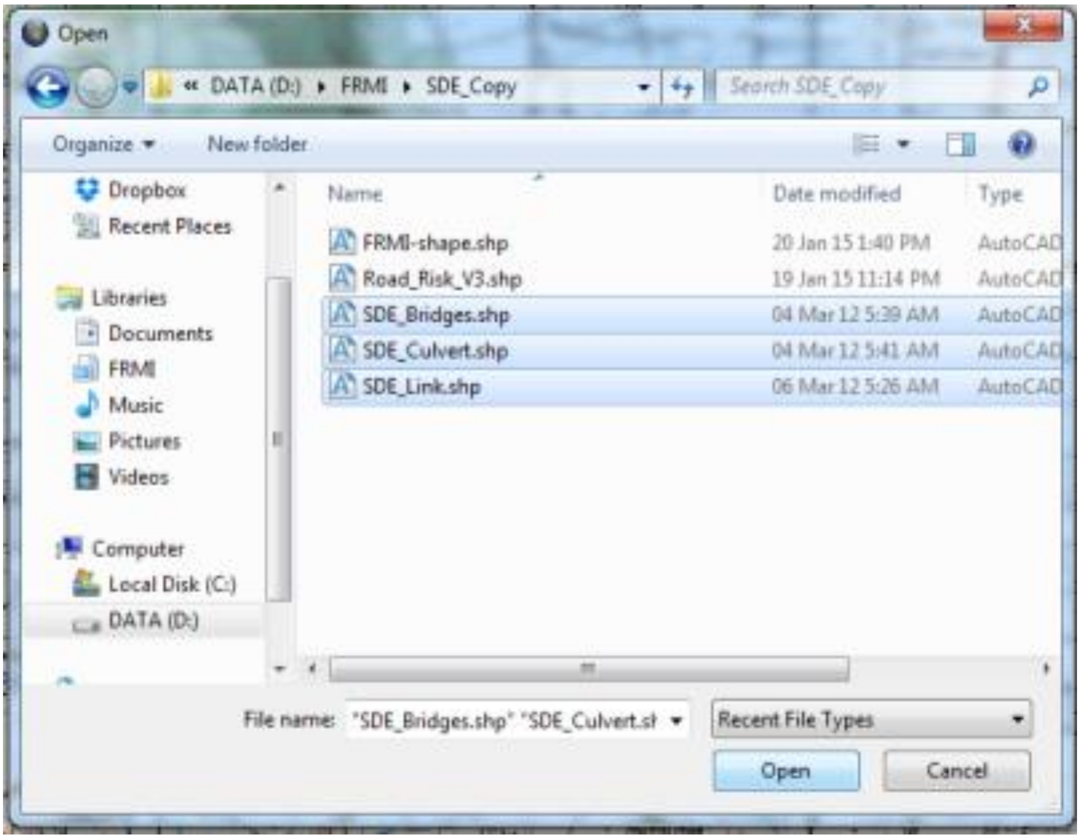
Load **locations of Culverts or Bridge and SDE_Link** for showing the roads in data shapefile into the Map. Navigate to:

Local (D): > FRMI> SDE_Copy> select the shapefile data of Culvert, Bridge and SDE_Link respectively or select all these files and Click Open.

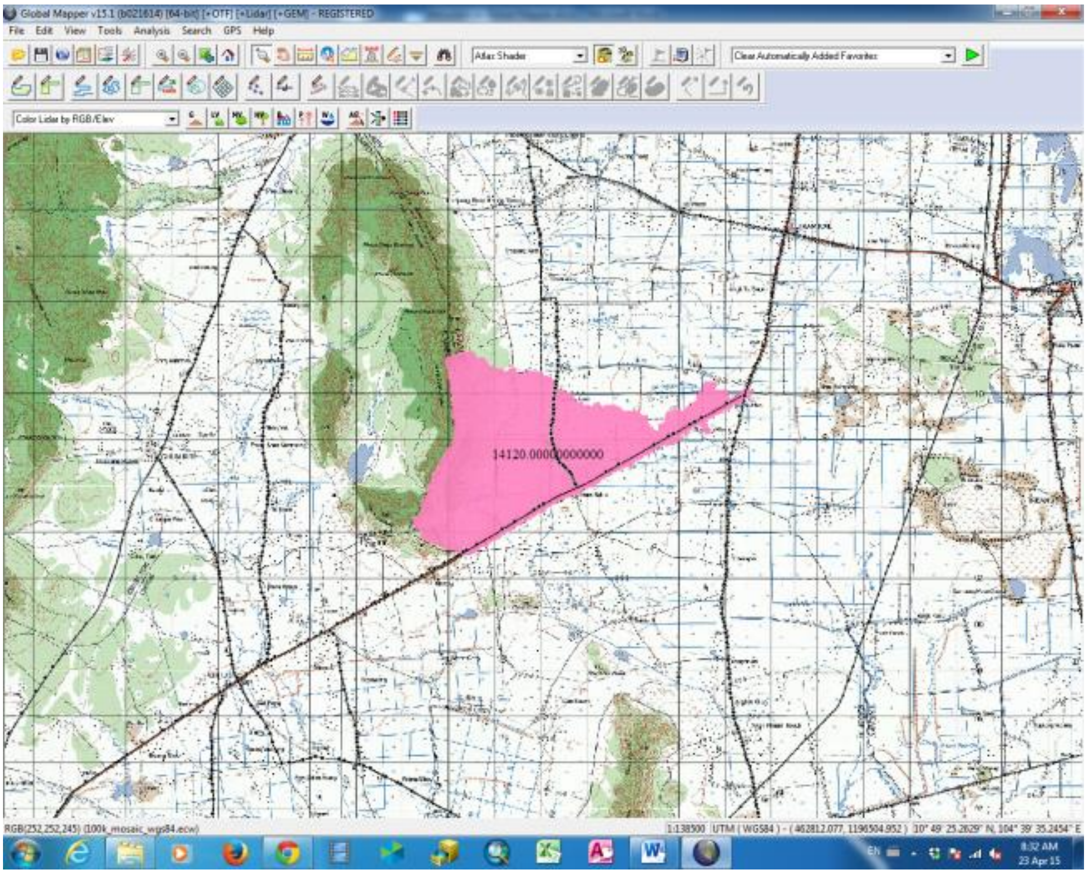
Load **terrain elevations**. Navigate to:

Local (D): > FRMI>ARC_GIS_WS>GIS_Data>Elevation>SRTM> select the files srtm_57_10 & srtm_58_10



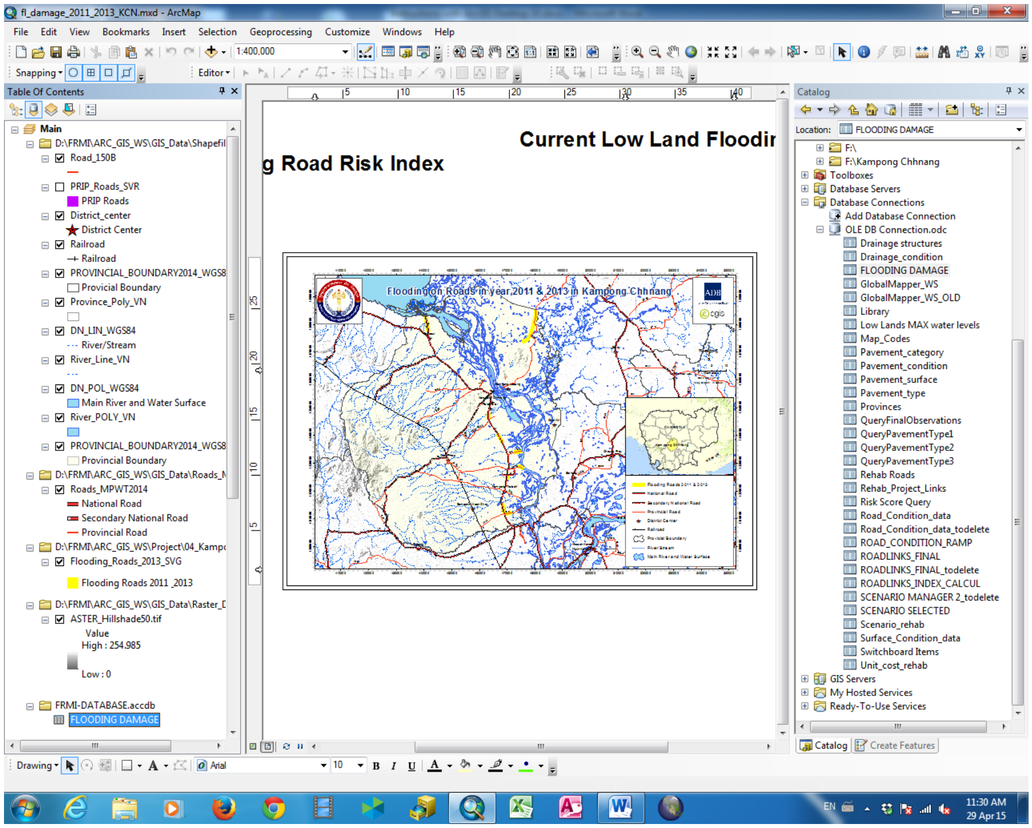


The map will be shown as below.

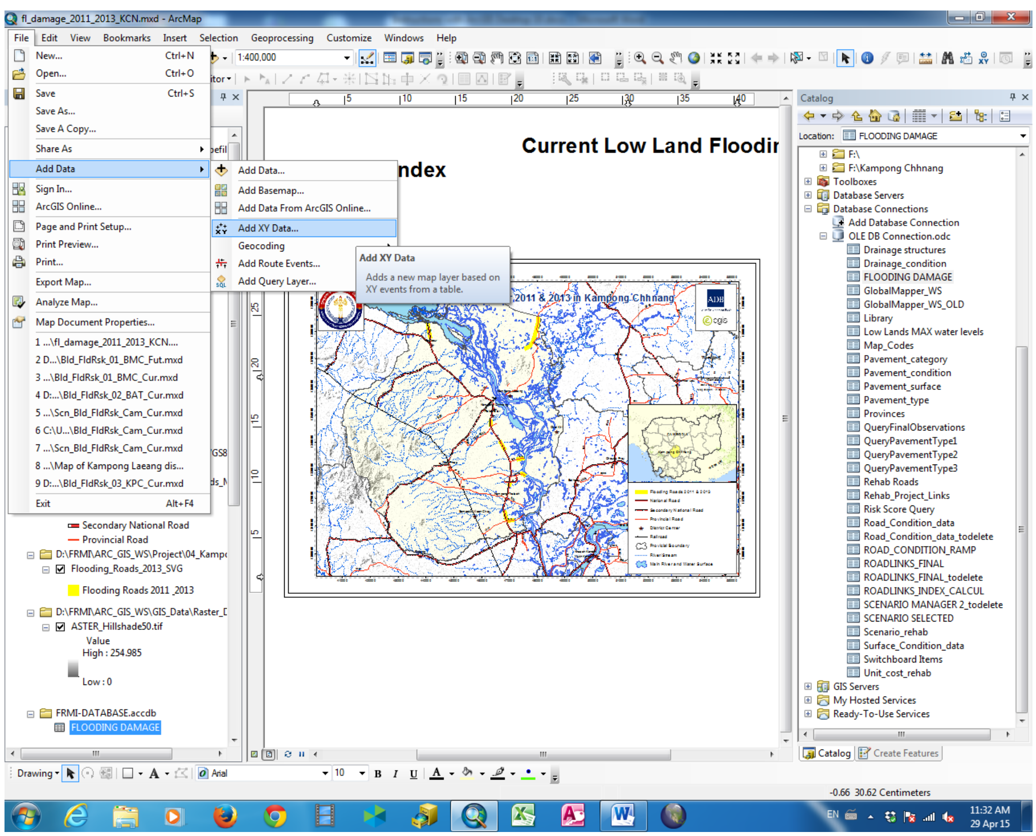


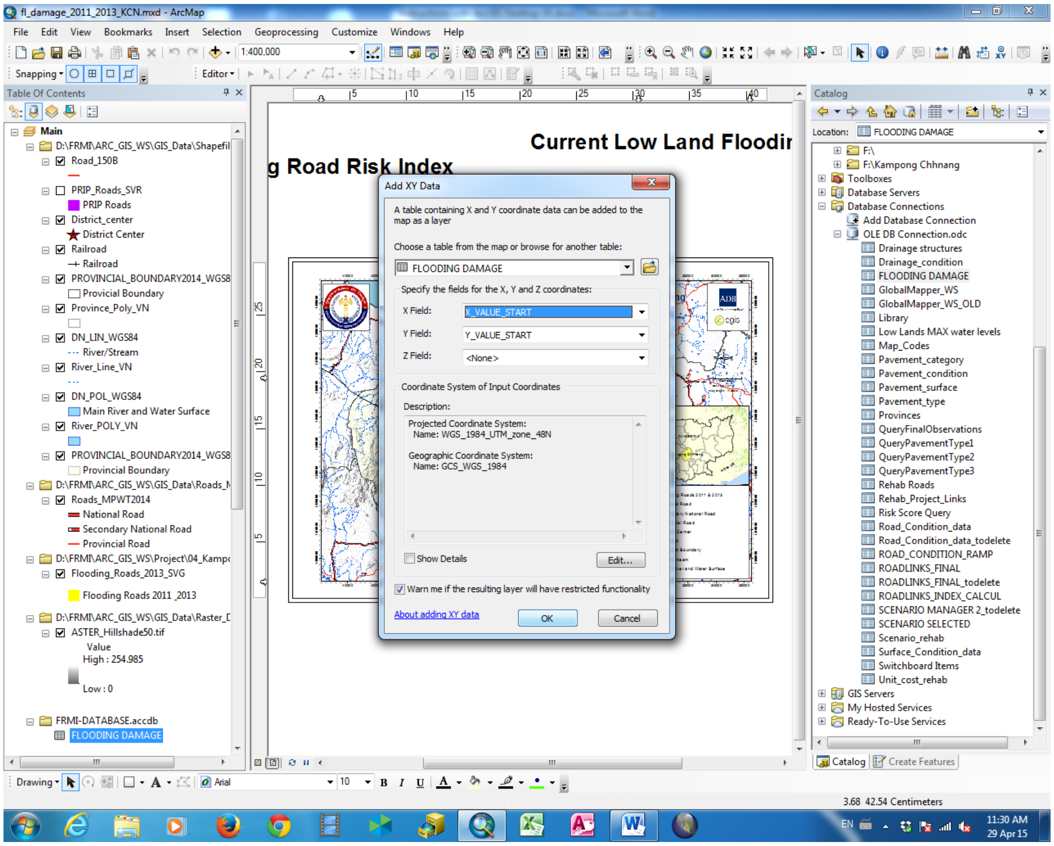
Appendix 14

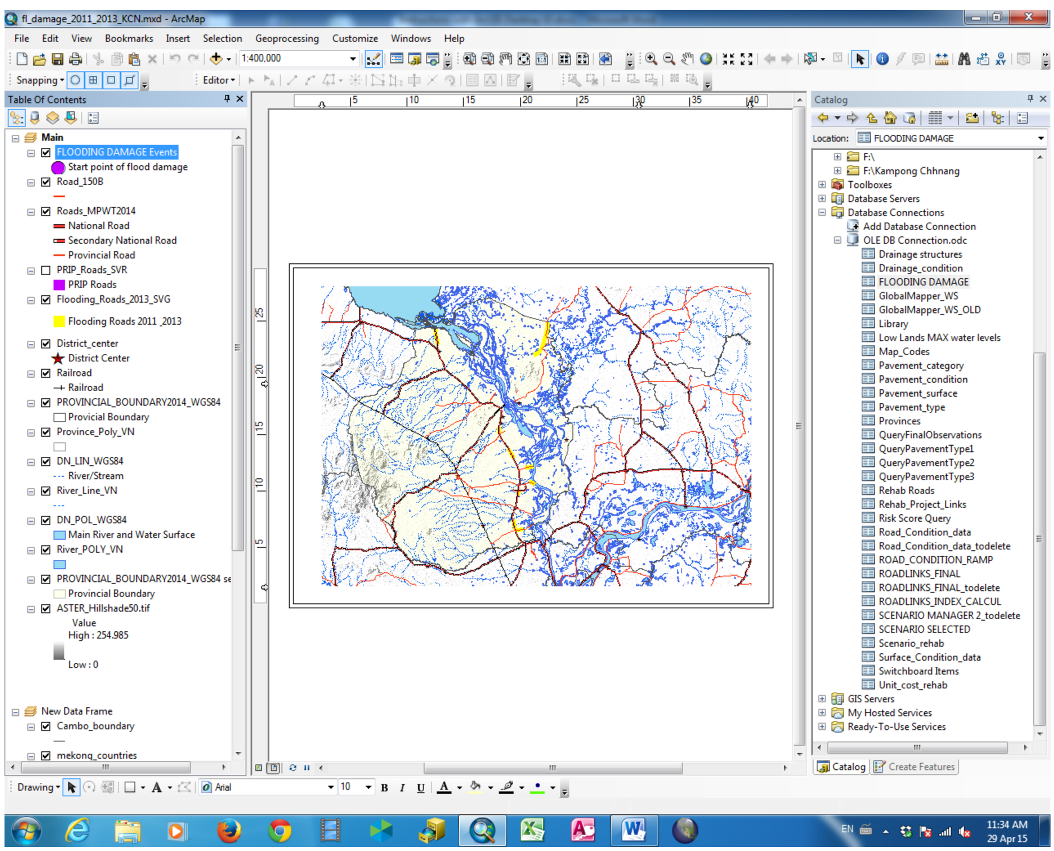
1. **How to create for linking ArcGIS Desktop to the coordinates points from external data**
    - **Open ArcGIS Desktop>ArcCatalog>OLE DB Connection.odc>Connect>**
    - **Click and drag FLOODING DAMAGE from ArcCatalog and drop into the Table of Contents (TOC)**



- **Add X,Y start point**







2. The point on the top of Table of Contents was created as a purple color

- **Add X,Y End point, do the same process as start point of flood damage**