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Developing a national programme of flood risk management measures: Moldova

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ABSTRACT. – A Technical Assistance project funded by the European Investment Bank has been undertaken to develop a programme of flood risk management measures for Moldova that will address the main shortcomings in the present flood management system, and provide the basis for long-term improvement. Areas of significant flood risk were identified using national hydraulic and flood risk modelling, and flood hazard and flood risk maps were then prepared for these high risk areas. The flood risk was calculated using 12 indicators representing social, economic and environmental impacts of flooding. Indicator values were combined to provide overall estimates of flood risk. Strategic approaches to flood risk management were identified for each river basin using a multi-criteria analysis. Measures were then identified to achieve the strategic approaches. A programme of measures covering a 20-year period was developed together with a more detailed Short-Term Investment Plan covering the first seven years of the programme. Arrangements are now being made to implement the programme. The technical achievements of the project included national hydrological and hydraulic modelling covering 12,000 km of river, the development of 2-dimensional channel and floodplain hydraulic models from a range of topographic and bathymetric data, and an integrated flood risk assessment that takes account of both economic and non-monetary impacts.

Key-words: National, flood, hazard, risk, investment, Moldova

Développement d'un programme national de gestion des risques d'inondation en Moldavie

RÉSUMÉ. – Un projet d'assistance technique financé par la Banque européenne d'investissement a été réalisé pour élaborer un programme de mesures de gestion des risques d'inondation pour la Moldavie, en vue de rectifier les principales lacunes dans le système actuel de gestion de ces risques et servir de base à son amélioration à long terme. Les zones à haut risque d'inondation ont été identifiées à l'échelle nationale à l'aide de modélisation hydrologique et hydraulique, et des cartes de l'aléa d'inondation ainsi que des risques d'inondation ont ensuite été préparées pour les secteurs les plus sensibles. Le risque d'inondation a été calculé en utilisant 12 indicateurs représentant les impacts sociaux, économiques et environnementaux dus aux inondations. Les indicateurs ont été combinés pour fournir une estimation globale du risque d'inondation. Des approches stratégiques pour la gestion des risques d'inondation ont été identifiées pour chaque bassin hydrographique à l'aide d'une analyse multicritères. Des mesures ont été ensuite identifiées pour implémenter ces approches stratégiques. Un programme de mesures portant sur une période de 20 ans a été développé ainsi qu'un plan d'investissement plus détaillé à court terme couvrant les sept premières années du programme. Des dispositions sont actuellement prises pour exécuter le programme. Les accomplissements techniques du projet incluent la modélisation hydrologique et hydraulique de 12 000 km de rivière, le développement d'un modèle bidimensionnel couvrant à la fois le lit des cours d'eau et leur plaine d'inondation, basé sur un éventail de données topographiques et bathymétriques, et une évaluation intégrée des risques d'inondation qui tient compte des impacts tant économiques que non monétaires.

Mots-clés : National, inondation, aléa, risque, investissement, Moldavie

I. INTRODUCTION

I.1. Background

Following severe floods in 2008 and 2010, the Government of Moldova requested assistance to improve flood protection throughout the country. A technical assistance project to develop a programme of flood risk management measures was financed by the European Investment Bank (EIB) under the Eastern Partnership Technical Assistance Trust Fund (EPTATF).

Moldova, as it is not a Member of the EU, had neither implemented the EU Water Framework Directive (2000/60/EC) nor the EU Floods Directive (2007/60/EC). However on 27 June 2014 the Republic of Moldova signed an Association Agreement and Free Trade Agreement with the EU. Under the Association Agreement the Republic of Moldova undertakes to gradually approximate its legislation to the EU legislation including the EU Floods Directive and the EU Water Framework Directive.

Thus the approach adopted in this project of implementing the steps set out in the EU Floods Directive is consistent with current legislation in Moldova. The approach set out in the EU Floods Directive has been extended in order to provide a programme for immediate implementation that would address the main shortcomings in the present flood

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management system, and provide the basis for the long-term improvement of flood management in Moldova.

I.2. The river system in Moldova

Moldova is a landlocked country with an area of 33 843 km^2. The river system in Moldova consists of two large international rivers, the Dniester and the Prut, and a large number of smaller rivers (Figure 1). The Prut forms the western border of Moldova with Romania. The Dniester forms the border between Moldova and Ukraine in the north of the country and then passes through Moldova for a distance of 475 km before re-entering Ukraine.

Figure 1 : *National flood hazard map*

67% of Moldova drains into the Dniester, 24% into the Prut and 9% into the Black Sea or the Danube via tributaries that cross the southern border of the country into Ukraine. The largest river in Moldova is the River Răut, which drains about 23% of the country. There are a large number of smaller rivers in generally narrow valleys. The rivers in Moldova have about 3,000 km of flood defences which consist of earth banks (dykes).

There are nearly 5,000 dams and reservoirs in Moldova ranging from two large hydroelectric dams, the Dubasari dam on the Dniester and the Costești Stânca dam on the Prut, to many small reservoirs near villages that were built for water supply and other purposes. Whilst these reservoirs can have beneficial impacts on flooding by attenuating flood flows in the rivers, there is a risk of dam failure with potentially catastrophic consequences.

I.3. Stages in the development of the programme of measures

The programme of measures was developed in the following main stages:

• Preliminary Flood Risk Assessment;
• Hydraulic modelling and preparation of flood hazard maps for high risk areas;
• Assessment of flood risk;
• Identification of objectives and strategies for flood risk management;
• Identification of measures for flood risk management;
• Development of the phased investment programme and the Short Term Investment Plan.

The approach to developing the investment programme including objectives and strategies for flood risk management generally follows EIB guidance [EIB, 2007].

II. PRELIMINARY FLOOD RISK ASSESSMENT

II.1. Summary

The availability of flood data in Moldova was limited, particularly on the smaller rivers. It was therefore decided to undertake national flood modelling in order to prepare the Preliminary Flood Risk Assessment (PFRA), as this would provide a consistent assessment of flood risk for the whole country. The results were checked against flood extents from historic flooding including the major floods on the Dniester and the Prut in 2008 and 2010.

High level hydrological and hydraulic modelling was therefore carried out for all 12,000 km of rivers in Moldova in order to identify flood hazard areas. The flood risk was calculated by overlaying the flood hazard map with a land use map, and weighting each land use type according to the flood impact. The risk was presented on a national flood risk map as high, moderate or low.

Lengths of river with high flood risk were selected for detailed assessment and covered a total river length of 3,400 km. This includes the full length of the Dniester and the Prut rivers that border or pass through Moldova.

II.2. National flood modelling

II.2.1. Method

The standard method for carrying out a flood hazard assessment involves a hydrological analysis, in order to calculate flood flows into the river reaches of interest, and then a hydraulic analysis to calculate river levels and flood extents. The method used for the PFRA was to apply rainfall to a Digital Elevation Model (DEM) of the whole country.

A DEM for the whole of Moldova was constructed using a national DEM provided by the Moldova government, which has a horizontal resolution of 35 m. It was also necessary to include river catchments that drain into Moldova from other countries, and the DEM for these catchments was obtained from a coarse resolution satellite DEM (SRTM). A rainfall-runoff model was then created for each of the catchments to assess runoff based on rain-gauge records, soil type, land cover type, area and slope.

Rainfall profiles with annual probabilities of 1% and 0.1% (return periods of 100 years and 1,000 years respectively) corresponding to rain gauges distributed within the country were directly applied to the elements in the DEM. The country was divided using Thiessens polygons in order to identify the area assigned to each rainfall profile. Given the high-level nature of the study, infiltration losses were represented by a simple fixed runoff percentage rate for different parts of the country.

This method has the advantage of not requiring any preliminary topography analysis to derive sub-catchments: the runoff follows the steeper slopes and naturally concentrates in drainage paths. It then flows into streams and rivers and the analysis included predictions of river flows, flood levels and flood extents.

A limitation to applying this type of method on such a scale has in the past been computer processing power. However the use of modern Graphics Processing Units (GPU) allows carrying out these simulations roughly an order of magnitude faster than with a multi-core Central Processing Unit (CPU), making this approach a practical possibility.

Flows for the Dniester and Prut rivers were based on gauged flow records. Most of the flood volumes come from outside Moldova and there are good gauge records for both rivers.

II.2.2. Results

Predicted river flows were calibrated against directly measured flows at river gauging stations where these data were available and of suitable quality. Comparing the results with calibration data, the modelled flows tended to be peakier than the recorded flows reflecting simplifications in the broadscale hydrological analysis. Adjustments were made to calibration parameters including ground surface roughness in order to achieve acceptable agreement between predicted and observed flood hydrographs at river gauging stations.

Flood extents predicted by the model for selected design flood events were combined with land use information (and therefore vulnerability) in order to produce a preliminary map of relative flood risk, which has enabled identification of the areas with the greatest flood risk.

A Geographical Information System (GIS) procedure was used to calculate relative values of risk per kilometre for all of the rivers, thus providing an auditable method of selecting the areas of greatest flood risk. Different land uses were assigned different values of impact, with the greatest impact applying to residential areas in cities, towns and villages.

The flood hazard map for Moldova is shown on Figure 1. The dendritic nature of the river system is apparent. The largest floodplains are on the Dniester and the Prut, particularly in the lower reaches. A 3D view of flood hazard for part of Moldova is shown on Figure 2. The large flooded area is a natural floodplain upstream of a gorge on the River Răut.

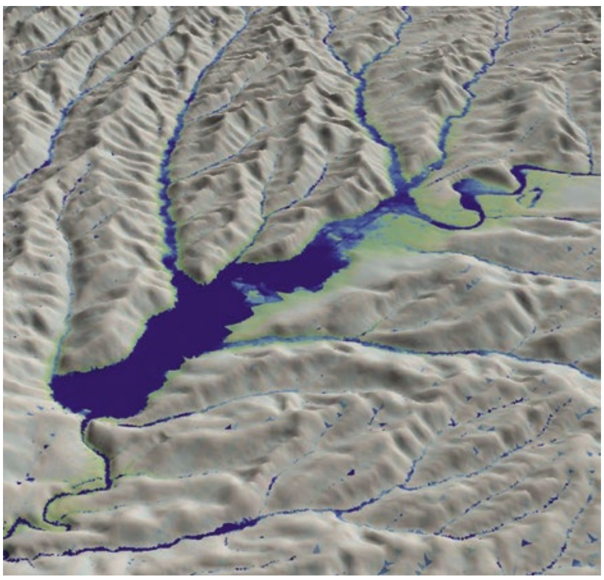

Figure 2 : *3D view of a section of the national flood hazard map*

III. FLOOD HAZARD MODELLING

Detailed hydraulic models were constructed for the 3,400 km of rivers that were identified as high risk rivers in the PFRA. Separate models were created for each river basin including the full length of the Dniester and the Prut rivers that border or pass through Moldova.

III.1. Data

Data collected for the hydraulic modelling and flood hazard mapping included detailed topographical data from a number of different surveys. A Light Detection And Ranging (LiDAR) survey for many of the rivers together with river channel and dyke surveys were carried out as part of the project. In addition, existing topographical data was collected from other projects in Moldova. The Agency of Land Relations and Cadastre provided LiDAR data for the central part of the country, funded by the Austrian Development Cooperation. River channel bathymetry and floodplain topography data for the lower part of the Dniester were provided by the Dniester III project [ENVSEC, 2012]. DEMs for each river basin were created by combining the various sets of topographical data.

A wide range of other data were collected for the detailed modelling including information on the dam structures and operational procedures. Collaboration with other projects to obtain data included a project to improve the operation of the Costeşti Stânca dam on the River Prut [EAST AVERT, 2013].

III.2. Creation of 2D models from 1D channels and 2D floodplains

III.2.1. Background

The classic and widely-used method for river flood modelling is to use a one-dimensional (1D) representation for the river channels and a two-dimensional (2D) representation for the floodplain [e.g. Alcrudo *et al*., 2005; L'homme *et al*., 2010]. Reasons for using this method include the limitations of channel bathymetry data, limited possibilities for representing hydraulic structures in 2D and limited computer resources that constrain the extent and resolution of 2D domains.

However the 1D-2D modelling approach has limitations including the need to determine the best location for the 1D-2D boundaries, weaknesses in methods for linking of 1D-2D domains in existing modelling software, and model instabilities at the 1D-2D interface.

As shown earlier, the use of GPUs can significantly decrease 2D simulations run time, and allows the use of either larger or more detailed meshes. This has been used here in order to represent river channels directly within the 2D mesh, via elements small enough to capture the bathymetry of rivers. The method requires careful preparation of a DEM where all the necessary topography and bathymetry from different sources are combined into a single 2D surface.

III.2.2. Creating the DEM

In order to create a consistent topography and bathymetry DEM, the first step was to prepare the topography for each river basin using the best available data at any single location including the high resolution LiDAR and the medium resolution 35 m DEM.

The second step consisted of creating a DEM of the river bathymetry. Bathymetry obtained from a boat mounted sonar survey was available in the lower part of the River Dniester from the Dniester III project (ENVSEC, 2012). However for most of the River Dniester, the River Prut and for some smaller rivers only 1D cross sections were surveyed.

Software has been developed as part of the in-house HR Wallingford research programme that interpolates a 2D surface along the river channels based on the river 1D cross sections. A straight interpolation would not lead to realistic results. Skew in the source cross sections was corrected, and the impact of contraction/expansion in-between cross sections was also taken into account, so that the interpolated channel width matches the actual river channel width at all locations.

Finally the topography and bathymetry have been merged in a single 2D surface which was used for the 2D model of each river.

III.3. Model results

Hydrological rainfall-runoff modelling was undertaken for each river basin to determine model inflows, except for the Dniester and Prut rivers where the inflows were calculated using gauged data. Hydraulic modelling for the 3,400 km of river was undertaken for floods with annual exceedance probabilities of 1%, 0.5% and 0.1% (return periods of 100, 200 and 1,000 years respectively). National flood hazard maps were prepared showing the flood extents for these events with and without the flood protection dykes. In addition, dam break modelling and mapping was carried out to identify the areas that would be affected by dam failures.

A small section of a flood hazard map is shown on Figure 3. Detailed maps showing flood depth and velocities were produced for each of the floods with different annual exceedance probabilities. It was found that for these large flood events, most of the existing flood defences were overtopped. In addition, the floods generally filled the river valleys and therefore the differences in flood extent between the 1%, 0.5% and 0.1% were small. However the differences in flood depths were large, typically in the range 0.3 m to 3 m depending on the size of river.

A climate change impact assessment was also carried out, in which the impacts of potential increases in future flood flows

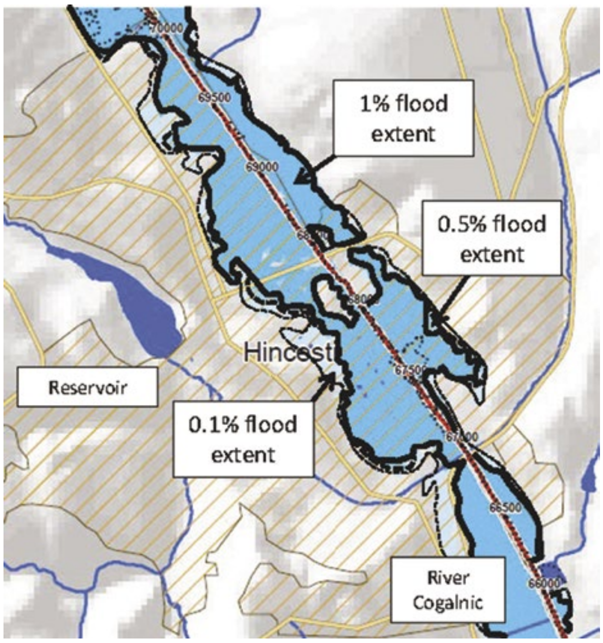

Figure 3 : *Section of a flood hazard map*

were investigated. The same pattern was observed: small changes in flood extent but large changes in flood depth.

IV. FLOOD RISK ASSESSMENT

The flood risk was calculated using twelve indicators representing human, economic and environmental impacts. These included the effects of flooding on people, property damage, agricultural damage, effects of flooding on environmental and cultural sites, and pollution. The twelve flood risk indicators are shown in Table 1.

The distinction between indicators HU1, HU2 and HU3 was based on the flood depth (*d*) and the flow velocity (*v*) obtained from the hydraulic modelling results, as follows (Defra, 2005):

For severely affected people: $(d \,.\, (v + 0.5)) > 1.5$

For very severely affected people: $(d \,.\, (v + 0.5)) > 2.5$

Table 1 : Flood risk indicators

Categories of impacts		Flood risk indicators
Human impacts	HU1	N° of **affected people**
	HU2	Number of **severely affected people**
	HU3	Number of **very severely affected people**
	HU4	Number of **water supply points** flooded
	HU5	Length of **key infrastructure** flooded (main roads, railways)
Economic impacts	EC1	Damages for **residential area** (cities, towns, villages)
	EC2	Damages for **non-residential area** (industrial and commercial)
	EC3	**Agriculture** damages
Environmental impacts	EN1	Area of **environmental sites** flooded
	EN2	N° of **heritage sites** flooded
	EN3	N° of **pollution sources** (WWTP, oil stations, waste disposal sites …) flooded
	EN4	Area of **diffuse source of pollution**

The flood risk was evaluated by calculating annual average impacts for each indicator and then combining the impacts to obtain the total risk. Damages for properties were calculated using depth-damage curves, as indicated on Figure 5.

Each flood risk indicator was "annualised " by using flood events with different return periods to estimate the long term annual average impacts. For example, the annual average number of people affected is an estimate of the number of people that may be flooded in an average year for each of indicators HU1, HU2 and HU3. This has been done by producing damage–probability curves. The total area under this curve represents the annualised value of the flood risk indicator, or to put it another way, the long-term average annual value of the flood risk indicator (Figure 6).

The flood risk indicators were combined by weighting each indicator. Whilst the flood risk was calculated as relative numbers, the economic indicators provide a direct economic cost and therefore the combined risk could be converted to economic damages.

The total annual flood risk for the 3,400 km of high risk rivers in Moldova was estimated to be €56 million. Almost half is due to direct economic damages and the remainder is due to indirect damages including human and environmental impacts. The average annual number of people affected by flooding was estimated to be 5,200, of which 44% would be severely affected and 15% very severely affected.

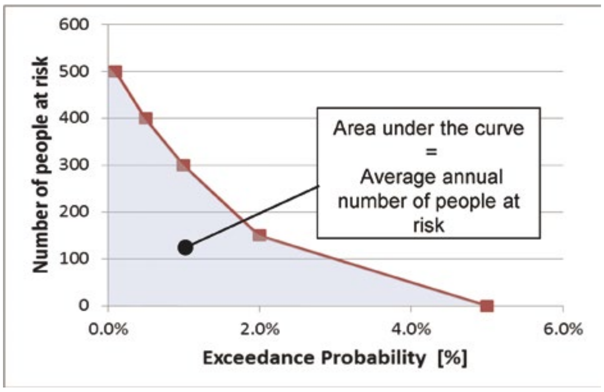

Figure 6 : *Calculation of annual average values*

The risk was categorised in terms of annual flood risk per 200 m x 200 m square as very high (> €25,000), high (€2,500 to €25,000), medium (€250 to €2,500) and low (< €250). The risk was plotted for 200 m x 200 m squares for all 3,400 km of river covered by the assessment. An example is shown on Figure 4. It would be possible to calculate the flood risk on a smaller and more refined grid, but the 200 m grid was considered suitable for estimating flood risk and the benefits of flood reduction measures at each location for flood management planning.

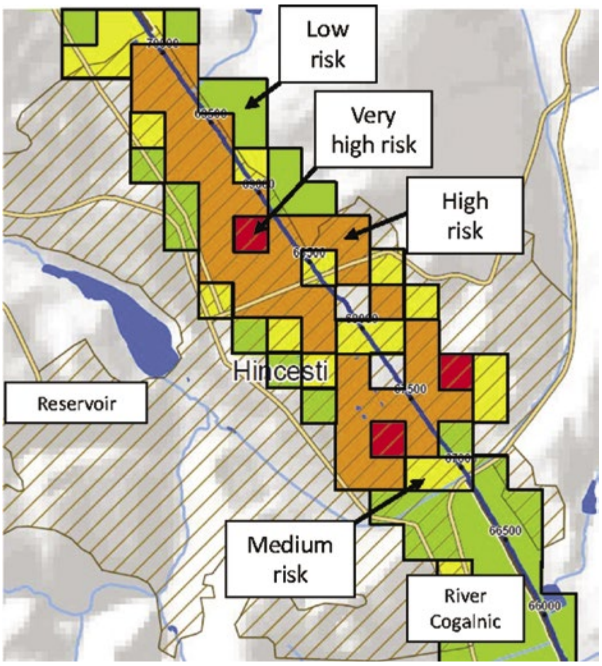

Figure 4 : *Section of a flood risk map*

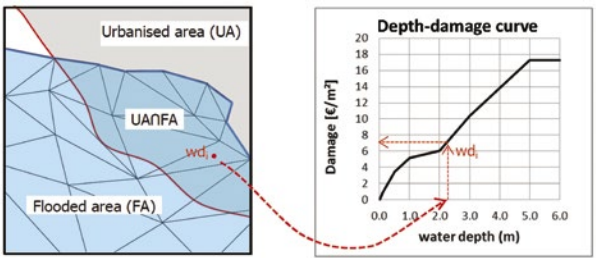

Figure 5 : *Calculation of damages for a residential area*

V. OBJECTIVES AND STRATEGIES FOR FLOOD RISK MANAGEMENT

Objectives for flood risk management were developed and agreed with stakeholders. These are the purposes of flood risk management, and the main objective identified by the stakeholders was to reduce flood risk to people and settlements. Protection of agriculture was also an important objective, but considered to be of less importance than people and settlements.

A range of strategies to achieve the objectives were identified, and preferred strategic options were selected for each part of the river system using a multi-criteria analysis. The strategic options took account of the existing flood protection infrastructure, which represents a major existing investment in flood protection.

Investment in new flood management measures depends to some extent on the condition of the existing measures: where the existing dykes are in good condition, the amount of repair work would be small, whereas where the dykes are in poor condition, the amount of repair work and associated cost would be high. A detailed condition survey was carried out of the flood protection dykes in order to estimate the probability of failure and the rehabilitation work required.

The main strategic options included the following:

- Rehabilitation and improvement of the existing dyke system, where improvement includes raising of crest levels and the construction of new dykes;
- New or rehabilitated flood storage dams at some locations;
- Enlargement of the river channels at some locations (using two-stage channels to minimise the environmental impact);
- New or improved flood forecasting and warning systems;
- Emergency planning and response including public awareness raising;
- Combinations of options.

Avoidance of increases in flood risk elsewhere was an important consideration in the development of the options, and options that could potentially increase downstream flood risk were combined with flood storage to mitigate this risk at some locations.

The river system in Moldova is highly engineered with straightened river channels and parallel dykes. The strategic options included re-naturalisation of the river channels and floodplains at some locations as a step to long-term environmental improvement of the river systems, although the flood reduction benefits for the large floods used in the analysis were relatively small.

Strategic options were identified for each part of the river system taking account of the location of the flood risk and constraints. A multi-criteria analysis was carried out in order to identify the preferred strategic options. The analysis involves scoring and weighting each option against the following criteria: effectiveness at reducing risk (i.e. the proportion of risk reduced by the option); cost of the option; benefit-cost ratio; environmental impacts of the option (positive and negative); social impacts of the option (positive and negative).

In order to calculate values for some of the criteria, particularly the effectiveness and benefit cost ratio of each option, it was necessary to prepare outline designs and calculate approximate costs.

VI. FLOOD MANAGEMENT MEASURES

Flood management measures were then identified for the areas with the greatest flood risk including both structural and non-structural measures. Flood risk is widespread on the rivers in Moldova and a total of 84 structural measures were identified to reduce flood risk for over 100 settlements. Many towns and villages are affected by flooding although the greatest risks are in the major cities of Chișinău and Bălți.

In addition, a total of about 30 non-structural measures were identified including capacity building, improving flood management information, improving inspection and maintenance of infrastructure, land use planning, catchment water retention, soil conservation, flood forecasting and warning, emergency planning and public awareness raising.

Costs were estimated for the measures on the assumption that the works would be carried out by local contractors as far as possible, and therefore local prices were used except where materials (such as new flood gates) and expertise were not locally available. The costs included capital costs of structural measures, costs for non-structural measures and maintenance.

The measures were prioritised based on the urgency of the measure, the magnitude of the reduction in flood risk, the benefit-cost ratio of the measure and the need to develop groups of measures that provide an integrated solution for a flood risk area. Constraints to implementation were also identified as this could affect the timing of implementation.

VII. PHASED INVESTMENT PROGRAMME

The phased investment programme for structural measures was developed taking account of the priority of the measures and the constraints. The programme for non-structural measures was developed taking account of the dependency between different activities, for example the need for capacity building before certain activities can be undertaken and the need to establish databases and programmes of work before inspection and maintenance activities can be carried out.

It is likely that the phased investment programme will begin in 2017 and continue until 2036. The programme will be carried out in the following three phases:

1. Short-term measures (year 1 to year 7)
2. Medium-term measures (year 8 to year 12)
3. Long-term measures (year 13 to year 20)

The overall programme cost for the phased investment programme is about €295 million for structural measures and €120 million for non-structural measures including maintenance.

The Short-Term Investment Plan includes structural measures for the River Prut, the River Dniester, the River Bîc at Chișinău and the River Răut and tributaries at Bălți. The cost of the structural measures is about €70 million together with about €37 million for non-structural measures including maintenance.

VIII. IMPLEMENTATION

In parallel with the development of the programme, capacity building was undertaken to facilitate the handover to local staff. This included handing over the modelling system and providing training to staff from the organisations responsible for flood management in Moldova. The project team included local staff, which also helped to increase the local flood risk management capacity.

The programme will be implemented by existing national government organisations. The lead organisation will be Apele Moldovei, which is the agency within the Ministry of Environment that is responsible for water management in Moldova. There will be a need to increase the number of staff employed by these organisations for flood management together with associated training and capacity building so that the organisations have the capabilities to undertake the required tasks.

IX. CONCLUSIONS

An investment plan has been developed for flood risk management in Moldova that includes a range of structural and non-structural measures. The technical achievements of the project include the following:

1. National flood hazard and flood risk modelling and mapping has been undertaken for the Preliminary Flood Risk Assessment.

2. Fully 2-dimensional (2D) river and floodplain models of major rivers (up to 500 km in length) including protected floodplains have been created from a range of data including 1D river cross-sections and 2D floodplain topography. The use of GPU technology has improved the speed of computer simulations.

3. A flood risk analysis has been carried out that evaluates and combines risk from a range of social, economic and environmental flood impacts.

4. Preferred strategic options for flood risk management have been identified for each part of the river system using multi-criteria analysis.

5. The measures required to implement the strategic options have been identified and prioritised in order to provide a programme of measures to be implemented over a 20-year period.

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