

**HRPP** 416

# Conveyance and sediment management. Is it worth it?

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Reproduced from a paper presented at: 44th Defra Flood and Coastal Management Conference Telford, UK 30th June - 2nd July 2009

### CONVEYANCE AND SEDIMENT MANAGEMENT. IS IT WORTH IT?

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#### **Key Words**

Maintenance, conveyance, flood risk management, RASP, CES

#### Abstract

The Environment Agency is currently developing System Asset Management Plans (SAMPs) for each of its Flood Risk Management Systems (FRMS). Across the Agency, the expenditure on conveyance and sediment management is significant. The benefit achieved for this expenditure is however not known and difficult to determine. Typical approaches to the assessment of flood risk fail to reflect changes in the conveyance and or sediment regime of a channel. As a result, they often suggest that channel maintenance contributes little (or unknown) flood risk management benefit. This is a serious omission and limits the development of effective and efficient management policy and investment planning.

This paper presents an innovative broadscale approach to explicitly estimate the benefit of channel maintenance activities (defined as actions taken to manage either the conveyance or sediment within a watercourse). The "benefit" is defined as the change in the economic damage (to residential and commercial properties) expressed as the Expected Annual Damages (EAD) arising through different management options.

The method utilises expert rules to translate postulated changes in the approach to management (of both the channel vegetation and river sediment) into changes of conveyance. Credible but broad scale methods based on the Conveyance Estimation System (CES) are then used to estimate the likely impact on these changes in conveyance into changes in river water level for a range of return period storm events. The impact of the change in water level is assessed translated to a change in flood risk through the so-called RASP High Level risk analysis tools and expressed as a change in the EAD.

Validation of the method is presented through three pilot sites from different Environment Agency Regions (Anglian, Thames and North West Region) and comparison with more detailed RASP analysis. The validated method is then applied at a national scale to 85 catchments of England and Wales to provide an assessment of the national benefit derived through the "Business as usual" management scenario as well as changed conveyance management activities.

#### INTRODUCTION

The Environment Agency is currently preparing System Asset Management Plans (SAMPs) for all of its Flood Risk Management Systems (FRMS). Critical evidence in supporting this process is an understanding of the value of the "defended benefits" within each FRMS.

The approach was adopted based on a simple modification of the RASP National Flood Risk Assessment model whereby the national flood risk was reassessed in the so-called "*no defences*" case. In this case, the defences were set to the local ground level and the Expected Annual Damages recalculated and assumed to indicate the ultimate benefit from the raised defences when subtracted from the standard NaFRA analysis with the defences in place.

A critical constraint on this approach is that it takes no account of the potential change the conveyance capacity of the in watercourse in the absence of management and hence. suggests that channel maintenance activities (understood as the conveyance and sediment management) have no economic benefit. This is a serious omission and this paper presents the methods developed to estimate the value of the channel maintenance at a national scale; an approach that is then verified against more local study.

#### What is conveyance?

Conveyance is a quantitative measure of the discharge capacity of a watercourse. It relates the total discharge to a measure of the gradient slope of the channel,  $K = Q / S^{1/2}$ , where K (m<sup>3</sup>/s) is the conveyance, Q (m<sup>3</sup>/s) is the discharge and S is the uniform gradient. The ability of a channel to convey water flow directly influences water levels. For example, an increase of flow resistance involves smaller flow velocities and greater water depths.

The Conveyance Estimation System, or CES (Defra/EA 2004), is a free software tool (http://www.river-conveyance.net/inde x.html#software) that enables the user to estimate conveyance or carrying capacity of a channel (McGahey and Samuels 2004). CES has been used in the project presented in this paper to determine water levels the "Conveyance Generator" (using module) and estimating roughness coefficients of vegetation and substrate "Roughness Advisor" (through the module).

Vegetation and its overgrowth is one of the main factors influencing flow capacity, hence river conveyance. Its influence is captured by roughness coefficients. The growth cycle of vegetation causes a variation of roughness coefficients during the year. Maintenance works, as for example cutting, vary the growth cycle of vegetation and hence the flow resistance.



Figure 1. Example of emergent reeds growing in the channel of Great Eau (left) and time variation of percentage of cover and unit roughness for this type of vegetation provided by the CES Roughness Advisor (right)

Sediment deposits can also influence the watercourse conveyance by reducing flow area. Dredging or desilting will contribute to increase it. In general, sediment management is considered a less frequent work than vegetation management.

As channel maintenance works modify the conveyance of watercourse they should be considered in the flood risk analysis that supports the flood risk management decision-making process.

# Setting the level of analysis detail and effort

The method presented here is focused at supporting a national assessment of benefits associated with conveyance management. The results however will be used to identify national and regional priorities and hence have to be fit for purpose.

The approach developed is therefore efficient to apply (a small overhead in addition to the typical NaFRA analysis). It uses only data available at a national scale (albeit with varying resolution and accuracy) and is sensitive to changes in conveyance and sediment management regimes.

#### OVERVIEW OF THE ANALYSIS METHOD

The method presented develops rules to translate changes in the management of channel vegetation and river sediment into changes of conveyance. This changed state of the channel is then translated into a change in the water level associated with a given return period flow. The impact of the change in water level is then assessed in terms of flood risk through the RASP enabling (NaFRA) models economic consequences to be established and integrated over all return periods to estimate an associated Expected Annual Damage (EAD).

These stages are described in more detail below. However, the interested reader is

referred to HR Wallingford (2008) for more detail on the method and its application to pilot sites.

## Definition of channel maintenance works

Within the context of this project, channel maintenance works are described as having the purpose to improve, increase or maintain the conveyance of watercourses. Three main scenarios are studied:

- *"Do nothing":* no maintenance works are performed so vegetation is let to growth increasing the roughness coefficients and sediments deposit in the channel and hence, decreasing the cross-sectional area
- "Business as usual": the normal management works performed in the reach. This is difficult to define at a national scale and of course depends on the local context. In consultation with a number of Area staff and after a review of Good Practice Guidance (CAPM 1997, EA 1998a and b), a standard "Business as usual" scenario has however been develop as follows: a percentage of 50% of vegetation is considered to be removed across the channel width and two cuts per annum are taken into account at different periods of the year depending on the type of vegetation. For example, for emergent reeds, the third most common species in UK according to the River Habitat Survey (RHS) Database, a first cut in August and a second one in October are considered.
- *"Increased maintenance":* an increase of maintenance works from the point of view of conveyance that is related to an increase of the amount of vegetation cutting. As for "Business as Usual" a standard "Increased maintenance" scenario has been developed. This repeats the "Business as Usual" scenario but increasing the percentage of cutting to 80%.

Table 1.	Vegetation	roughness	coefficients	and	rules	to	estimate	total	roughness	for the
	most com	mon species	s in UK							

Type of vegetation	Do nothing			Business as usual	Increased maintenance		
	n <sub>x</sub>	Rule	n <sub>v</sub>	Rule	<u>n</u> <sub>x</sub>	Rule	
Mosses	0.015		0.015	$n = \left(n_{\nu}^{2} + n_{s}^{2}\right)^{1/2}$	0.015	$n = (n_{\nu}^2 + n_s^2)^{1/2}$	
Filamentous algae	0.015		0.015	0 - 0 - ( 2 2 ¥/2	0.015	$n = 0.8 n_{\rm s} + 0.2 (n_{\rm v}^2 + n_{\rm s}^2)^{1/2}$	
Emergent broad-leaved plants	0.150	$n = (n_v^2 + n_s^2)^{1/2}$	0.150	$n = 0.5  n_{\rm s} + 0.5 (n_{\rm v}^2 + n_{\rm s}^2)$	0.150		
Emergent reeds	0.060		0.049	( 2 2)1/2	0.032	$n = (n_{\nu}^2 + n_s^2)^{1/2}$	
Submerged broad and fine leaved plants	0.050		0.028	$n = (n_{\nu} + n_{s}^{-})$	0.020		

#### Translation of maintenance works into changes in conveyance (Vegetation management)

Maintenance works modify the shape and roughness coefficients of the main channel. For each management scenario the vegetation roughness coefficient is obtained with the Roughness Advisor of CES. This tool provides seasonal patterns of vegetation roughness based on current knowledge and expert advice. If the growth curve of vegetation is known, the curve is modified in the CES according to the maintenance works to obtain a new averaged annual vegetation roughness value. The total roughness in the channel is then defined combining roughness values for vegetation,  $n_{\nu}$ , and substrate material,  $n_s$ . For the "Do Nothing" option, the vegetation roughness provided by the Roughness Advisor is not modified. As the substrate is not affected by maintenance works, their roughness values remain constant for the different management scenarios considered.

If the roughness value of vegetation does not vary along the year (because there is not any growth curve set up in the tool), a rule (defined in Table 1) is considered to determine the total roughness coefficient.

The following table shows the vegetation roughness coefficients and the rules applied to calculate the total roughness, n, for the most common species in UK and for the different management scenarios

#### Translation of maintenance works into changes in conveyance (Sediment management)

For the "Do nothing" scenario the shape of the channel is modified to consider sediment deposition. This assumption simulates the withdraw of dredging works performed as normal maintenance.

No all watercourses are, however, prone to sediment deposition. Stream power is used as an indicator to help identify those reaches that may be susceptible to deposition. The "Stream power" indicates the relative balance of energy in the river on a reach scale level. It has been used by geomorphologists and ecologists as a method of taking an initial decision on how a river channel might be potentially affected by processes of erosion or deposition. It is considered as providing a reasonable high level indicator as to whether or not more sediment deposition is an issue and whether or not more detailed sediment modelling is required (Jacobs, 2007). Nevertheless, this method is fairly crude with only limited published applications relating to river management problems.

The stream power is estimated as:

 $ω = \rho g Q S / B (W/m2)$ 

where  $\omega$  is the stream power unit (W/m<sup>2</sup>),  $\rho$  the specific weight of water (kg/m<sup>3</sup>), g the acceleration due to gravity (m/s<sup>2</sup>), Q the bankfull discharge (m<sup>3</sup>/s), S the bankfull slope and B is the channel width.





Figure 2. Overview of methodology

A value of  $\omega$  less than 35W/m<sup>2</sup> is considered as indicative of sedimentation problems although threshold values cannot be taken prescriptively due to very limited datasets available. The amount of sediments deposited is estimated as a reduction of 10% of the channel depth (based on some field data).

In the "Business as usual" and "Increased maintenance" scenarios, no improvement or detrement to the sediment regime is assumed.

## SUMMARY OF THE ANALYSIS STEPS

The detailed steps of the analysis method are listed below and summarised in Figure 2.

#### **Definition of cross-sections**

The river network and information about defences at a SAMP polygon level are obtained using advanced in-house GIS tools. The model is based on the definition of cross-sections along the river network where water levels are calculated for each management option. Cross-sections are created at 1/20th below the upstream end of a reach, 1/20th above the downstream end and in the middle of a reach. A river reach is defined as a reach with no junctions or bifurcations on it. If a reach is less than 300 m long, only one cross-section is created at the midpoint of the reach.

#### **Cross-section profiles**

The National Composite DTM is used to extract cross-sections profiles. It is a 5m resolution grid, based on SAR data LIDAR combined with data where available. For narrower rivers, a 5m grid is not sufficient enough for an accurate description of channel and banks. A stable shape cross-section defined by the bankfull width, B, and height, h, (parameters obtained from the RHS database) is used to simulate the shape of such narrow channels. A national grid with interpolated B and hvalues is created from the existing RHS database (Figure 3).

In the "Do nothing" scenario it is considered that some cross-section may be prone to deposition and hence, the flow cross-sectional area could be reduced.

The stream power unit is estimated in each river cross-sections to identify which of them are prone to deposition. If the stream power is less than 35 W/m2, a reduction of 10% of the channel height due to sedimentation is considered. CES is used to estimate the bankfull discharge required to determine the stream power.

#### **Roughness coefficients**

Roughness coefficients in the channel are determined depending on the type of vegetation and predominant substrate. The type of vegetation and substrate are obtained from a grid with interpolated substrate and vegetation information created from the existing RHS Database (Figure 4). No distinctions are made between bed and banks.

The CEH Land Cover Map 2000 is used to define roughness coefficients in the floodplains. The land class values are transformed into unit roughness values using the information provided by the Roughness Advisor of the CES.

For the "Business as Usual" scenario and "Increased Maintenance" the roughness coefficients are modified considering the values and rules presented in Table 1.

#### **Calculation of water levels**

Once the cross-section profile and roughness coefficients are defined, water levels are estimated with the CES "Conveyance Generator" module in each cross-section for the different management scenarios and for the different return periods.





Figure 3. RHS field data points with information of B and h (left) and grid interpolated from that information containing the values of B and h (right)



Figure 4. Grid with interpolated substrate and vegetation in the Irwell Vale pilot site; BO\_MO=Boulders & Mosses, CO\_FA=Cobbles & Filamentous Algae, CO\_MO= Cobbles & Mosses

For each cross-section, water discharges for a range of return period events are obtained from the Centre for Ecology and Hydrology (CEH) Database. The values considered are Qmedium, and water discharges associated to 5, 10, 25, 50, 100, 200 and 1000 year return period. Water discharges are selected by snapping the information from the CEH database to the Detailed River Network (DRN) provided at a national scale.

Calculations of water levels are done in a two-steps basis: first water levels are calculated in the in-channel, which was raised by the defence height of each bank, and secondly, the floodplain is considered when water discharge starts to spill over.

Differences in water levels between different scenarios, "Do nothing" and "Increased Maintenance" minus "Business as usual", are calculated in each selected cross-section.

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An ArcGis tool has been developed to use the water level differences at specific crosssections with the RASP/NaFRA tools in order to calculate the Expected Annual Damage (EAD). Water level differences at each defence are calculated using linear interpolation between cross-sections.

#### Estimation of EAD

The flood risk estimation is based upon the Risk Assessment for Systems Planning approach (RASP) used in the National Flood Risk Assessment (NaFRA) covering the whole of England and Wales. RASP uses a risk-based approach to factor in the location, type, condition and effects of flood defences. The method involves the integration of a full range of loading conditions (river water levels associated to different likelihood calculated in previous steps) with the performance of defences, represented through fragility curves. This is allied to a flood spreading method, the so-called Rapid Flood Spreading Method (RFSM), which estimates flood depths over the floodplain area. This enables economic consequences related to the depth to be established, expressed as an Expected Annual Damage (EAD).

#### APPLICATION TO PILOT CATCHMENTS

Three pilot catchments were used to develop and validate the method, namely:

- Great Eau (Anglian region) in Lincolnshire; a predominantly rural catchment
- Crondall system, located at the upstream end of the river Hart (Thames region), with no raised defences hence, where the conveyance of the channel is a key parameter to provide protection
- Irwell Vale, a river in the area of Great Manchester (North West region), with no maintenance works related to vegetation but to dredging and desilting.



# Figure 5. Pilot sites used to develop and validate the methodology at high level

Application of the method to these three pilot sites shows that the influence of channel management is most important for low water discharges where the water levels are contained in the in-channel or where they just start to spill over the floodplain. At higher flows the impact of channel management is decreases (i.e differences between scenarios decrease as the discharge return period increases). This effect is shown in Figure 6.

Based on these changed water levels the change in the probability of inundation was then calculated using the RASP NaFRA model. These results are shown in Figure 7.

The RASP NaFRA models also enable the change in economic consequences due to property damage to be estimated and expressed as a change in the Expected Annual Damage (EAD). These results highlight that the variations in risk are very case dependent reflecting the development and spatial aggregation of the properties local to the pilot water course. Hence, it is difficult and misleading to develop general rules that relate changes in EAD to changes in channel management, For example, the increase of EA due to Do nothing option is 47% in Great Eau and 7% in Crondall.



Figure 6. Water level differences between the "Do Nothing" and "Business as Usual" scenarios averaged along the reaches of the three pilot sites for different return periods.



Changes in Probability of Inundation for the three scenarios: Do Nothing (Top), Business as Unsual (Middle) and Increased Management (Bottom) in Great Eau





2.5

5

#### COMPARISION WITH LOCAL MORE DETAILED STUDIES – PAMS

The Performance-based Asset Management System (PAMS) project is an EA research project to produce a decision support tool developing a "risk and performance-based" approach to asset management. In that, The Great Eau was chosen as a site to demonstrate the method for ascertaining the attribution of flood risk to defences in terms of EAD and evaluation alternative asset management options. Detailed information of cross-section shapes and current and possible management works have been used to calculate water levels associated to the different management scenarios with a 1-D hydraulic model. The results obtained at a detailed level (HR Wallingford 2009), with more precise inputs and elaborate tools, have been compared with those obtained at the high level to assess the reliability of national estimation of benefits.

The differences between "Do Nothing" and "Business as Usual" scenarios at both levels, high and detailed, though obviously different, show the capability of the methodology developed at a national scale to capture the behaviour of results. In Table 2 the EAD figures obtained from both cases show almost the same EAD difference between "Do Nothing" and "Business as Usual" scenarios though values at national scale are a bit higher than in the detailed level.

# Table 2. EAD (in £) for both scenariosandconsideringdifferentlevels of analysis

Management	EAD (£)				
scenario	High	Detailed			
	level	level			
Do nothing	139,033	111,742			
Business as	94,787	67,991			
usual					



Figure 8. % of increase in the EAD in the "Do Nothing" scenario compared with the "Business as usual" in 7 catchments in the Thames Region (catchments identified by its code number)

### APPLICATION AT A NATIONAL SCALE

Once the method was validated, it was applied, in the context of an EA project, at a national scale to estimate the benefits of maintenance works in the 84 catchments of England and Wales. The management options "Do nothing" and "Business as usual" were compared to estimate the benefits of maintenance works. Some of these results, just for 7 catchments, are showed in Figure 8 where the increase of EAD (expressed as a percentage) of the "Do nothing" option was estimated compared with the "Business as usual" scenario. This kind of results allows asset managers making decisions considering the benefits, effectiveness and efficiency of management.

#### CONCLUSIONS

A method to estimate the economic benefits associated with the maintenance of channel conveyance that can be applied at a national scale has been developed and demonstrated in the context of three pilot sites: Great Eau (Lincolnshire), Crondall (Thames region) and Irwell Vale (Great Manchester).

Expert rules to translate postulated changes in the management of channel vegetation and river sediment into changes of conveyance have been developed and applied.

Credible, but broad scale, methods to translate these changes in conveyance into changes in river water levels for a range of return period flows (based on the Conveyance Estimation System) have also been developed and demonstrated. Existing RASP tools have been utilised to translate these changes in water level into changes in flood risk; expressed as EAD for the different management scenarios.

The method described has been developed at a high level and applied at national scale. The quality of the national databases used, as River Habitat Survey Database, Detailed River Network, etc, defines the reliability of the results. Although it has not been possible to undertaken a formal uncertainty analysis, comparison with more detailed studies shows a favourable comparison.

#### RECOMMENDATIONS

The method developed has been proved to be robust and reliable to estimate at a high scale the benefits of maintenance works when applied to three pilot sites and compared with more detailed studies. Nevertheless, more detailed information available would improve the definition of:

- cross-sections
- the type of vegetation and substrate of the channel
- maintenance regimes

Further possible improvements of the method are related to the development of theoretical knowledge on the definition of reaches prone to sedimentation and of vegetation growth curves (to determine the roughness coefficients).

It is also possible to improve the calculation of water levels considering backwater effects or the afflux of structures as bridges or culverts

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